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# Transient Ejector Analysis (TEA) Code User's Guide

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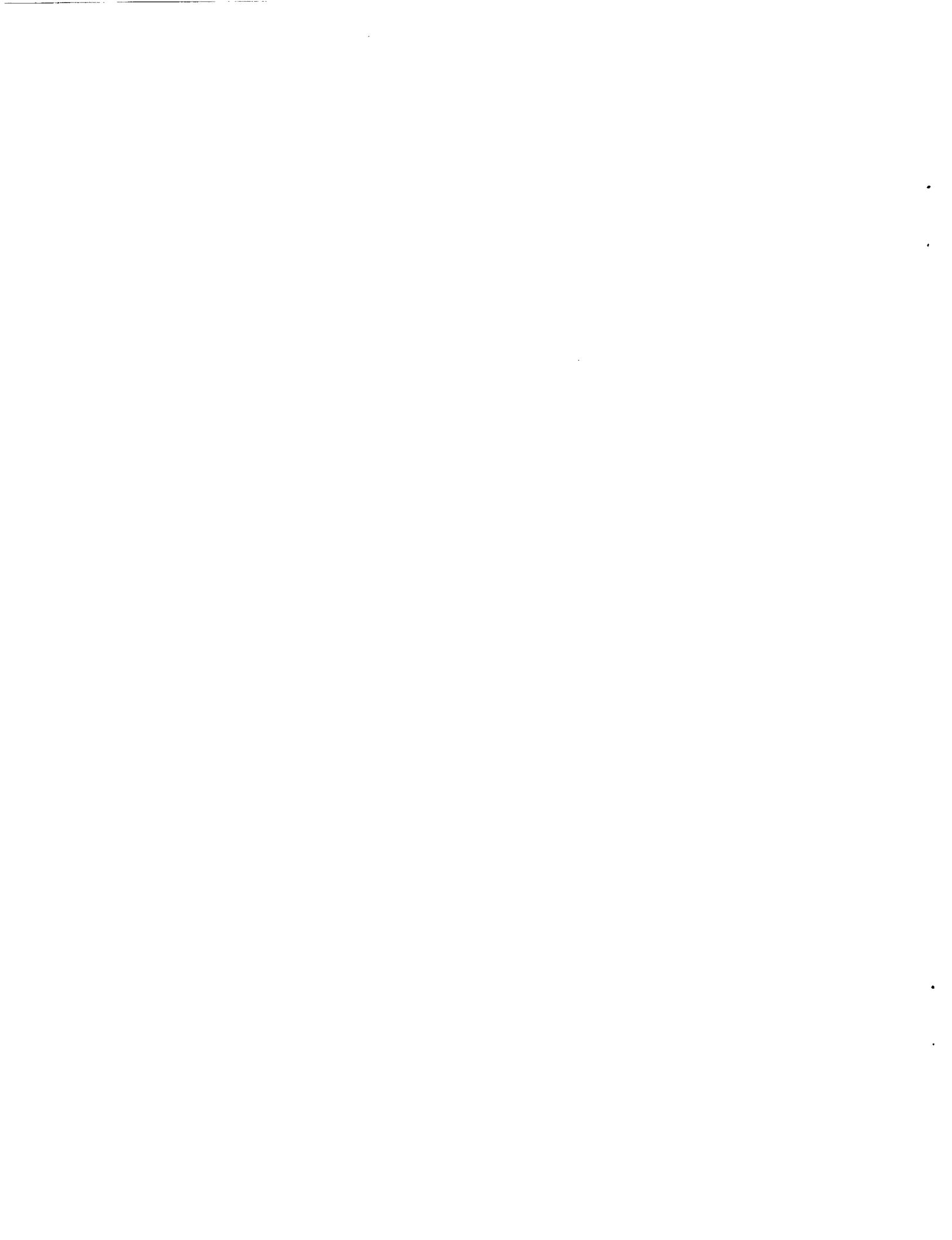
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## TRANSIENT EJECTOR ANALYSIS (TEA) CODE USER'S GUIDE

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### SUMMARY

A FORTRAN computer program for the semianalytic prediction of unsteady thrust augmenting ejector performance has been developed, based on a theoretical analysis for ejectors. That analysis blends classic self-similar turbulent jet descriptions with control-volume mixing region elements. Division of the ejector into an inlet, diffuser, and mixing region allowed flexibility in the modelling of the physics for each region. In particular, the inlet and diffuser analyses are simplified by a quasi-steady-analysis, justified by the assumption that pressure is the forcing function in those regions. Only the mixing region is assumed to be dominated by viscous effects.

The present work provides an overview of the code structure, a description of the required input and output data file formats, and the results for a test case. Since there are limitations to the code for applications outside the bounds of the test case, the user should consider TEA as a research code (not as a production code), designed specifically as an implementation of the proposed ejector theory. Program error flags are discussed, and some diagnostic routines are presented.

### CODE OVERVIEW

TEA is a FORTRAN computer program (TEA.FOR), designed for batch execution, which reads an input file (TEA.DAT) to obtain the necessary program data (ejector geometry, primary nozzle conditions, free-stream conditions), solution control options, and file output requests for print and plot files (TEA.OUT and TEA.PLT, respectively). An overview of the TEA.FOR program follows; the required TEA.DAT input file structure is the subject of the next section.

The main program simply serves to open the necessary I/O files and instructs the processing of input data, after which the governing equations are solved.<sup>1</sup>

A total of three subroutines are contained in the TEA.FOR file;<sup>2</sup> they are

- DIP - Data Input Processor
- MEC - Main Execution Control
- SPC - Single Point Calculation

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<sup>1</sup> The solution procedure can be influenced by input file specifications.

<sup>2</sup> Appendix B provides a complete listing of the TEA.FOR file. Some idea of complexity is given by code length: the code is 731 lines long, divided into 21 lines for the main program, 164 for the DIP, 57 for the MEC, and 569 for the SPC. Programming style leans toward clarity rather than conciseness. The development platform for this code was a VAX 8800; the code has not been tested on other platforms.

Figure 1 illustrates that the SPC routine is called by the MEC routine. Although the primary purpose of this document is to provide instructions for preparation of the TEA.DAT file (read by the DIP), some brief remarks on each program module are helpful in interpreting the overall program structure.

### Module Descriptions

Data input processor. — The data input processor (DIP) is designed to obtain baseline ejector engineering information, free-stream properties, solution control options, and printout and plot control parameters from the input data file and place this information in COMMON blocks; the use of COMMON blocks reduces (or eliminates) the need for READ statements in other program subroutines.

Input data is read from TEA.DAT according to a macro command sequence. The DIP echoes essential program data (specified and default) so the user can conveniently identify incomplete or incorrect input data. In the interest of clarity, the DIP routine was not written as compactly as possible; this is an overriding perspective throughout the code. For ease of use, all data has a free-format structure — the user need only demarcate values with a comma, rather than be concerned with the customary Hollerith and data format (e.g., 2F12.3).

Main execution control. — The main execution control (MEC) routine provides the basic service of feeding the single point calculation (SPC) subroutine argument list with the information needed to compute ejector thrust at a specified point in time. Although it may appear the MEC is a trivial routine to include, it facilitates development of an SPC that is void of I/O for the time-dependent primary flow conditions.

A previously mentioned aspect of the DIP and MEC subroutine structure is the absence of subroutine calls — all information is transmitted through COMMON blocks. While this may not be the most effective programming practice,<sup>3</sup> it is an approach that met the simulation specifications at the time the code was under development.

Single point computation. — The single point computation (SPC) subroutine is the focal point of the TEA program and provides the code implementation of the transient ejector theory given by Drummond (ref. 1). Execution of the SPC routine is controlled by the MEC, since the SPC is structured to be a “drop-in” module for integration in, for instance, an aircraft engine simulation. The SPC is the largest program subroutine, consuming almost two-thirds of the overall TEA code (see lines 243-731 of the listing in Appendix B).

Information for the SPC routine is transmitted primarily through COMMON blocks. This influence on the TEA computer program was the result of a requirement that the SPC argument list include only the primary flow conditions ( $m$ ,  $T_{1P,0}$ ,  $P_{1P}$ ) at a given time  $t$ , and return thrust and augmentation ratio ( $T$ ,  $\phi$ ) for a real-time component-level-model engine simulation.<sup>4</sup> This requirement is clearly simulation specific, but does provide module parameter inputs consistent with information

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<sup>3</sup> The COMMON block chalkboard approach to programming can make program error tracking during diagnostics a difficult process.

<sup>4</sup> As discussed by Drummond (ref. 1), the motivating factor behind the development of the transient ejector theory was the need to develop a high-fidelity propulsion system simulation for the Advanced Short Take-Off and Landing (ASTOVL) development program.

typically available to an engine simulation code.<sup>5</sup> Although alternate simulation requirements may result in the need for a different SPC argument list, the modular code structure remains quite convenient.

Comment cards in the SPC routine mark out blocks of calculations corresponding with calculation steps in the theory; an outline of the SPC solution procedure is shown in figure 2.

Within the SPC module, there exists a decision branch between quasi-steady and transient flow calculations, based on the value of an execution mode switch, MODE, in the SPC argument list; this points to an important aspect of an ejector mixing region analysis. Since it is expected that transient ejector performance predictions are kicked-off from an assigned initial condition (there can be more than one initial condition of interest), there is a need for a built-in initialization routine for the field variables. A quasi-steady solution to the governing equations is associated with a value of MODE=0; such a solution does not invoke time derivatives in the analysis and provides, by default, a series of steady-state flow computations. When MODE=1, a transient solution is invoked which reflects the implementation of the proposed transient ejector theory.

System of units. — Few applications in engineering analysis appear to be exempt from the need to clarify the system of units involved in calculations. Typically, confusion extends from translating back and forth between force, mass, and pressure; the usual remark is that a consistent system of units must be used in analysis, and that certainly is the case here. In the present work, the Engineering English system of units is used.

With the backdrop that the current work represents a research code, the use of the Engineering English system was appropriate for the system simulation during the code development period (in which this code was ultimately intended to be compatible with a propulsion system simulation that used a similar unit system; the Metric system was not appropriate for the simulation application).

The Engineering English system is based on four fundamental units for length, force, time, and mass. Units of length are in feet (ft), units of time are in seconds (s), units of force are in pounds-force ( $\text{lb}_f$ ), and units of mass are in pounds-mass ( $\text{lb}_m$ ). Compatibility of units is provided by the introduction of the gravitational constant  $g_c = 32.174$  into Newton's law ( $g_c$  is numerically, but not dimensionally equal to the gravitational constant). Although the work of Drummond (ref. 1) provides extensive examples on the appropriate units for each variable involved in the analysis, the following summary is relevant to input file preparation:

Description	Mnemonic	Value = Units
Temperature	T	= $^{\circ}\text{R}$
Pressure	P	= $\text{lb}_f/\text{ft}^2$
Velocity	V	= $\text{ft}/\text{s}$
Density	RHO	= $\text{lb}_m/\text{ft}^3$
Mass flowrate	MDOT	= $\text{lb}_m/\text{s}$
Specific heat ratio	GAMMA	1.4 = non-dim
Gas constant	RBAR	1715.66 = $\text{ft}^2/\text{s}^2\text{R}$
Angle of attack	ALPHA	= degrees

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<sup>5</sup>This leads to certain calculations that normal ejector codes would not have a requirement for, or the use of (e.g., a total pressure versus static pressure specification at the secondary inlet).

In principle, there is nothing to prevent the user from using, say, the Absolute MKS system of units ( $g_c$  has a value of unity) since equations involving the value of  $g_c$  do so symbolically. Illustrations of this are shown in lines 118 and 122 of the SPC routine —  $g_c$  is set at the top of the SPC module (line 67) and could be reassigned as desired.

## INPUT DATA FILE PREPARATION

### Typical File Structure

Data processing for the TEA.FOR program involves extensive use of macro commands; macros are keywords placed in the input file which permit a flexible input data file structure. Appendix A provides an example<sup>6</sup> input file structure.

Although the macro command structure can be perceived as a somewhat clumsy programming practice, the result is a very lucid input file structure. Another benefit to the macro approach is that the blocks of data are not required to be placed in any particular order, and in some cases they need not appear at all (as long as the program defaults are acceptable to the user). A subtle feature of the macro command approach is that the program will ignore any lines that do not begin with a recognized keyword — as such, the user can include as many descriptive comment cards as desired at the top of the file for a full description of the case study at hand.<sup>7</sup>

### Macro Commands and Options

Within the data input processor (DIP), solution instructions, data input, and data output specifications are read from the TEA.DAT file through a macro command structure. As mentioned previously, COMMON statements are extensively used as placeholders in memory to shuttle data from one routine to another. Except for the SPC, none of the subroutines have argument lists since the necessary information is provided by the COMMON statements. For this type of data transfer, sub-program macros are very useful.

Data to be processed within the DIP block is subdivided according to a logical characterization of the data to be handled. Currently, eight keywords are used in the subdivision of data:

'BACK'PRESSURE	Back pressure specification for ejector discharge (optional)
'CASE'	Case banner for printed output (optional)
'COEF'FICIENT	Empirical coefficients for mixing and entrainment
'DISP'LAY	Display control for printed and plotted output (optional)
'FREE'STREAM	Free-stream fluid properties
'GEOM'ETRY	Geometry of the ejector
'PRIM'ARY	Primary nozzle discharge conditions
'STOP'	Stop command for data input processing (optional)

<sup>6</sup> This file corresponds with the test case to be discussed later; for now, however, it is the file structure rather than the numbers themselves that are of interest.

<sup>7</sup> After several weeks pass, it is easy to forget why a particular case was of interest.

Quotes around the first four letters of each keyword are used to indicate the minimum portion of the word to be included for data file preparation. Only four of the eight data blocks are essential to include in the input file; optional sets are marked accordingly. Except for STOP, which (if used) must be the last keyword encountered in the DIP data block, the keywords and associated data can occur in any sequence desired. Descriptions of the input parameters associated with each macro command are given below (in alphabetical order).

**BACK:** Ejector back-pressure (optional). — Aircraft installation aerodynamics often dictate that the back pressure of an installed ejector may be different than atmospheric; to accommodate this, the BACK block allows the prescription of a nonatmospheric exit pressure.

Line	Variable	Description
1	'BACK'	Keyword for back pressure input block
2	'PBACK'	Value for ejector back pressure [Default: PBACK=PINF]

This data block is optional if the back pressure is equal to that of the ambient since the program default is to assign the backpressure to the value of the free-stream static pressure (as specified and discussed later in the FREE stream block). PBACK has units of lb./ft.<sup>2</sup>.

**CASE:** Banner for printed output (optional). — The descriptive banner is the header for printed output. This data block is composed of two lines:

Line	Variable	Description
1	'CASE'	Keyword for banner input block
2	'RUNID'	Banner for printed output [Default: RUNID='TEA']

The CASE block is optional; the program provides a default banner of TEA if this data block is omitted.

**COEF:** Coefficients for solution type, mixing, kinetic energy entrainment. — As discussed in the work of Drummond (refs.1 and 2) the ejector theory implemented in this work employs two empirical constants, the flow mixing effectiveness, BETA ( $\beta$ ), and the coefficient for the kinetic energy transfer function, CSIGMA ( $C_s$ ).

Line	Variable	Description
1	'COEF'	Keyword for coefficient data block
2	'TITLE'	Comment line with descriptive titles for variables on next line
3	'ITYPE', 'BETA', 'CSIGMA'	Type of solution desired (0 = Steady; 1 = Transient) Mixing effectiveness factor (1.0 < BETA < 2.0) Kinetic energy coefficient (0.0 < CSIGMA < 1.0)

In the interest of making direct comparisons between quasi-steady and full transient flows, this block introduces the option of enforcing a quasi-steady flow assumption. What essentially happens is that the steady-flow initialization routine is invoked for all point calculations emanating from the MEC. The default integer has a value of ITYPE=1 and marks the full transient flow as the execution mode; a value of 0 eliminates time derivatives to provide the quasi-steady option (ITYPE sets the value of the MODE parameter discussed previously in the SPC overview).

DISP: Printout of intermediate computations (optional). — For detailed investigations of transient performance calculation results, three parameters can be set to control printed output and plot file information.

Line	Variable	Description
1	'DISP'	Keyword for display data block
2	'TITLE'	Comment line with descriptive titles for variables on next line
3	'ICHECK', 'INDEX', 'IPLOT'	Integer for printed calculation output [Default: ICHECK=100] Indexing for printout loops [Default: INDEX=1] Index for plotfile data [Default: IPLOT=0]

Values of ICHECK can range between 0 and 1000, where 0 provides no printed output at all, 50 provides only a print summary from the DIP and MEC routines, and a value of 100 (the default) provides detailed listing of SPC results as each time step calculation is completed.<sup>8</sup> For diagnostic applications, ICHECK = 500 provides detailed velocity initialization data, and at ICHECK = 1000, self-similar profiles and secondary velocities are printed for every iteration within each time step. The INDEX parameter is useful if the program has operated on, for instance, 500 primary nozzle states, and it is desired to only printout every 10th computed result; INDEX must have a value greater than or equal to 1. The IPLOT parameter dictates whether a plot file is to be created, and the intervals at which data is written to the plot file. For the default value of IPLOT = 0, no data is stored in the TEA.PLT file. For IPLOT = 1, primary flowrate, thrust, and thrust augmentation are stored at each time interval; for values of IPLOT = N, every Nth data point is stored (much like the INDEX function).

Plot file output parameters are controlled by the WRITE statement at lines 231-235 in the code. At present, only parameters passed through the SPC argument list are amenable to place in the plot file; other parameters could be used if the appropriate WRITE statements were written to replace the existing segment of code.

FREE: Free-stream fluid properties (optional). — Characteristic (free-stream) flow properties and thermodynamic data are contained in the FREE stream data block.

Line	Variable	Description
1	'FREE'	Keyword for free-stream data block
2	'TITLE'	Comment line with descriptive titles for variables on next line
3	'TINF', 'PINF', 'GAMMA', 'RBAR', 'UINF', 'ALPHA'	Free-stream static temperature [= 530°R; default value] Free-stream static pressure [= 2116.8 lb./ft <sup>2</sup> ] Specific heat ratio [= 1.4 nondim] Universal gas constant [= 1715.66 ft <sup>2</sup> /s <sup>2</sup> R] Free-stream velocity [= 0.0 ft/s] Angle of attack [= 90.0 deg]

To simplify the implementation of the ejector theory, the primary and secondary ejector streams are assumed to have the same gas composition (this is not a restriction of the theory).

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<sup>8</sup> The rationale for the ICHECK values of 0, 50, 100 (instead of 1, 2, 3) extends from the prototype code effort to interface with the airframe simulation.

GEOM: Ejector geometric characteristics. — Geometric approximations for the ejector are contained in the GEOM data block. All numeric data must be proceeded by a title. Data is expected in the following order:

Line	Variable	Description
1	'GEOM'	Keyword geometric data input block
2	'TITLE'	Comment line with descriptive titles for variables on next line
3	'X0,Y0'	Inlet (station 0) x- and y-dimensions
4	'TITLE'	Comment line with descriptive titles for variables on next line
5	'X1,Y1, NX1,NY1'	Primary nozzle (Stn 1) x- and y-dimensions x-section Number of nozzles in the x,y- directions
6	'TITLE'	Comment line with descriptive titles for variables on next line
7	'X2,Y2'	Secondary flow (station 2) x- and y-dimensions
8	'TITLE'	Comment line with descriptive titles for variables on next line
9	'X3,Y3'	Mixing region (station 3) x- and y-dimensions
10	'TITLE'	Comment line with descriptive titles for variables on next line
11	'X4,Y4'	Diffuser exit (station 4) x- and y-dimensions
12	'TITLE'	Comment line with descriptive titles for variables on next line
13	'Z1,NZ1'	Total mixing region length and number of finite volumes

Figure 3 illustrates the expected geometric layout of the ejector; specific data was shown previously in Appendix A.

PRIM: Primary nozzle discharge conditions. — This block specifies the primary nozzle discharge velocities and thermodynamic properties.

Line	Variable	Description
1	'PRIM'	Keyword for primary nozzle data block
2	'TYPE'	Keyword for nature of data to follow: 'SPEC' -> Data specified for every t 'STEP' -> Step function specification

If TYPE = 'SPEC', then the following input data sequence is expected:

Line	Variable	Description
3	'TITLE'	Comment line with descriptive titles for variables on next line
4,...N	'T(I), DMPDT(I), T1P0(I), P1P(I)'	Time stamp Primary flowrate Stagnation temperature Static pressure
N+1	0	Number(s) or character(s) to trigger end of record

Note that there are four data values on each of the 4,...N lines to simulate the primary nozzle conditions as a function of time. The N+1 reading must be a number or letter format that will terminate input by triggering an error in the READ loop (a simple single value of '0' works fine; see Appendix A).

If TYPE = 'STEP', then the following input data sequence is expected:

Line	Variable	Description
3	'TITLE'	Descriptive comment for variable list
4	'T(1)	Starting time
	DMPDT(1)	Starting primary flowrate
	T1P0(1)	Starting stagnation temperature
	P1P(1)'	Starting static pressure
5	'TITLE'	Comment line with descriptive titles for variables on next line
6	'Z1TIME'	Time at which step-change occurs
	Z1DMDT	New primary flowrate
	Z1T1P0'	New stagnation temperature
	Z1P1P'	New static pressure
7	'TITLE'	Comment line with descriptive titles for variables on next line
8	'TSTEP,N'	Time-step size and number of time steps to take

STOP Statement (optional). — The end of input data is marked by the presence of the QUIT card.

Line	Variable	Description
1	'STOP'	Keyword to exit DIP routine

## ILLUSTRATIVE CASE

### Background

Research on design methodologies for integrated aircraft and flight control systems requires accurate subsystem component simulations. In principle, these simulations must mimic steady-state and transient component effects. Of particular interest in recent years is the development of real-time simulations for short take-off vertical landing (STOVL) aircraft.<sup>9</sup> The thrust augmenting ejector shown in figure 4 is considered a potentially valuable propulsion subsystem element for the powered-lift aspect of STOVL aircraft.

Steady-flow ejector performance predictions are typically the centerpiece of an ejector design cycle, and transient flow behavior is most often described through a quasi-steady flow approximation. The latter essentially assumes away the transient behavior issue since the conjecture is the ejector will instantaneously provide whatever thrust is demanded.

To establish the validity of the quasi-steady flow assumption, one must be able to quantify the elapsed time for the ejector to adapt to a new thrust level, and establish that the ejector delay is less than the control system update period. In air-breathing propulsion systems, this assessment can take the form of a comparison between the ejector frequency response and that of the propulsion control system; see figure 5. The purpose of the TEA program is to assist in the assessment of the ejector response rate; the specific case study used to examine the STOVL response rate is presented next.

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<sup>9</sup> For more extensive details on the simulation of interest, see Drummond (ref. 2), or Drummond and Ouzts (ref. 5).

## Characteristic Test Case

In the absence of appropriate<sup>10</sup> data from transient flow ejector experiments or from advanced time-dependent CFD calculations, verification that the proposed ejector analysis can provide reasonable thrust predictions must be left to engineering judgement. Because of this, a familiar forcing function must be used. In the present work, the system response to a step-function input is not only a characteristic transient case study, but the scenario is coincident with typical STOVL ejector application. For demonstration purposes the ejector system response to a step-change in primary nozzle flowrate from 18.7 to 21.85 lb<sub>m</sub>/sec is chosen because (1) experimental steady-state data at each of these operating points is available, and (2) the 17 percent change in primary flowrate is beyond the small-perturbation range; this exercises the system nonlinearities. Two versions of the TEA.DAT input file were prepared<sup>11</sup> for this case study and are given in Appendix C.

Geometric approximations for the ejector inlet, mixing region, and diffuser are presented in table I note the 3-D to 2-D conversion required for the primary nozzle area. This conversion in nozzle geometry is required so that the input data will be consistent with the mathematical formulation of the ejector mixing layer.

## Results

For the mixing region, a finite-volume length of 0.18 ft and a characteristic mixing region velocity of 500 ft/s, the characteristic time step for computations is approximately 0.4 ms. To avoid infringing on this stability limit a computational time step of 0.1 ms was chosen; 100 time steps provided the necessary interval for examination of the step-function test case.

A detailed listing of the program printout is given in Appendix D, though the results for each of the 100 time steps are not shown (for brevity).

The empirical coefficient in the transient analysis (required for calibration of the primary-to-secondary kinetic energy exchange mechanism), was selected to match the asymptotic thrust prediction with the quasi-steady value at the new set point. Figure 6 illustrates the predicted ejector thrust profile for a coefficient  $C_e$  of approximately 0.25. It appears the 2 millisecond residence time of the flow (elapsed time for the primary nozzle flow to reach the diffuser exit plane) is slightly less than the 3 millisecond interval for the thrust to reach a new maximum. Oscillations in thrust after that point appear to settle out in about 5 milliseconds.

An (initially) unexpected feature of the thrust profile is the dip in thrust immediately following the step-change in primary nozzle efflux. Examination of the field variable profiles reveals this is not a numerical problem, but that the increase in static pressure associated with the instantaneous change in driving flow temporarily impedes the secondary flow. After a short period, the secondary flow kinetic energy builds to overcome this effect and then continues in the intuitively expected manner.

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<sup>10</sup> A test was conducted by Drummond (ref. 3), specifically to collect transient ejector data, but the forcing function had a characteristic time much greater than the time scale of interest in simulation validation.

<sup>11</sup> The file identifier 'TEA.DAT' is hard-coded into the program for simplicity in program development. As such, the examples given in Appendix C are titled CASE1.DAT and CASE2.DAT, for which it is assumed the user will rename the case of interest to be TEA.DAT, prior to execution. The user can automate this process through a simple command language script.

## Discussion

Steady-state ejector performance is well-known to be highly sensitive to design conditions, so it should come as no surprise that the transient performance prediction task is as much an art as it is a science. Some aspects of the illustrative test case runs are useful to discuss.

Entrainment coefficient variation. — A critical step in the implementation of the transient ejector theory is the identification of the appropriate value of the empirical entrainment coefficient  $C_e$ . For a known ejector step-function response, the desired  $C_e$  value is the one that provides a match between the predicted asymptote and the known thrust at the second state. As an example, thrust predictions for various  $C_e$  values are shown in figure 8; this chart illustrates the idea that the TEA code was not designed to provide the optimal prediction of steady-state ejector performance<sup>12</sup> — rather, that the code focuses on analysis of transient flow characteristics. (Figure 7 differs slightly from figure 6 in thrust prediction due to a slight modification in the implementation of the theory; figure 7 is the more recent result).

Back pressure effects. — It is possible for several physical reasons that the ejector backpressure will differ from the (upstream) ambient as, for instance, in the case of installation effects or curved mixing regions (asymmetric mixing region). To this end, a performance feature to explore is backpressure limits. The principal goal of increasing the backpressure for any parametric investigation is to establish the threshold at which the mixing region discharge energy is inadequate to overcome the back pressure — in that situation the program notifies the user that a fatal error has occurred (see Appendix A). For the illustrative test case, the backpressure cannot exceed 5 percent over ambient. Error codes are discussed further in the ERROR CODES AND EXECUTION PROBLEMS section.

Performance sensitivity to nozzle geometry. — Ejector performance is very sensitive to ejector geometry. In particular, performance is most readily influenced by the primary nozzle discharge area. For the baseline case, a 20-percent increase in the primary nozzle area yields a 14-percent decrease in primary nozzle discharge velocity, but a 20-percent decrease in the primary nozzle area causes some difficulty in initialization of the program. As illustrated in Appendix A, the initialization difficulty is presented to the user through an error message for a negative entrained velocity. However, during the initialization process, a simple fix is to reset the entrained kinetic energy to a small positive number. This patch seems to work well in the few cases it has been invoked.

A point to be made here is that the ejector transient flow solution involves a highly complex solution logic, and that to encounter an error is not so much a reflection that the input data is incorrect, but that an idiosyncrasy with the solution method may have been encountered.

The discussion in the next section suggests that previous problems encountered with execution have been fixed by altering input data values. Recommendations for algorithm changes or improvements to the theory are outside the scope of this work.

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<sup>12</sup> But a sample routine is included to initialize the transient flow calculation procedure.

## ERROR CODES AND EXECUTION PROBLEMS

### Error Codes

At several points in the previous discussion, it has been noted that program execution may terminate under certain conditions. Five types of errors are currently flagged by the computer; although one could easily inspect the code and potentially identify many more diagnostic flags, those included presently extend from execution experiences with the test case described earlier. Error codes, the current flag location (given by the SPC line number), and a brief description of the problem are given below:

Error code	SPC line number	Description of problem
001	272	Imaginary value ( $B^2 - 4AC < 0$ in the quadratic equation) has been computed for the centerline velocity during initialization of the field variables. If ICHECK has been set to 500, then the XCHECK2 routine will assist in the diagnostics by printing a listing of the variables related to the calculation.
002	416	A negative value for the nominal velocity $V^*$ has been computed ( $V^*$ is equal to the entrained velocity $V_e$ , cubed). In this case, rates of change in KE have diminished entrainment rates to unrealistically low (negative) levels. The XCHECK3 routine is automatically invoked as a first pass at fixing the problem. (This was discussed in the test case description; see Performance Sensitivity to Nozzle Geometry).
003	448	Unrealistic value for density, the value is less than zero.
004	449	Unrealistic value for density, the value is greater than one.
005	452	Unrealistic value for temperature, the value is less than zero.
006	466	Stagnation pressure at station 4 is less than the static pressure; this results in an unrealistic discharge exit velocity. Either the ejector back pressure is too high or the inlet Mach number is too low.

These problems are generally symptomatic of the divergence of the transient solution.

### Execution Problems

Unrealistic or divergent transient flow solutions may be the result of one of the following:

- (1) An incorrect starting solution (check input data file),
- (2) Too large a time step (modify the input data time history), or
- (3) An inappropriate expression for the function for exchange of kinetic energy between the primary and secondary fluid streams.

The last item is an important one since the entrainment function relies heavily on the assigned value of CSIGMA (see line 185 in SPC). More details on this function and its origin are described in Drummond (refs. 2 and 4).

#### Optional Debug Routines

Appendix B includes four routines that may be useful for printout of intermediate information during the debugging process. These routines are invoked through INCLUDE statements (to simplify their omission or modification, if desired); typically, these diagnostic routines are unnecessary if the program executes without error.

Routine name	SPC line number	Description
XCHECK1	203	Printout of self-similar profile coefficient values
XCHECK2	273	Printout of data involved in the centerline velocity calculation; used in conjunction with SPC error code number 1.
XCHECK3	417	Corrective procedure for negative V* result; used in conjunction with SPC error code number 2.
XCHECK4	494	Entrained velocity error and discharge mass error printouts, used to monitor convergence of a solution at a given time step.

#### CONCLUSION

Understanding and quantifying ejector fluid-dynamic characteristics is central to design decisions involved in propulsion system applications. The present work provides instructions for a FORTRAN computer program implementation of a semianalytic prediction of unsteady thrust augmenting ejector performance developed by Drummond (ref. 1). That analysis blends classic self-similar turbulent jet descriptions with control-volume mixing region elements. Division of the ejector into an inlet, diffuser, and mixing region allowed flexibility in the modelling of the physics for each region.

An overview of the code structure, a description of the required input and output data file formats, and the results for a test case were presented. It is emphasized that there are limitations to the code for applications outside the bounds of the test case, so the user should consider TEA as a research code designed specifically as a test of the proposed ejector theory. For program applications outside the test case bounds, some error flags and diagnostic routines are presented and discussed.

## APPENDIX A - CODE SAMPLES

### TEA.DAT: SAMPLE

C-----CASE1.DAT---  
C  
C Case study input file for TEA.FOR transient ejector analysis  
C routine. Here a single step function is prescribed that  
C corresponds with one of the DeHaviland/PLF tests run in June 1987.  
C This file assumes that the default BACK and DISP parameters in the TEA.FOR  
C source code are appropriate.  
C  
C-----

CASE banner.

Test #2, Step change in primary flow for 87 DHC ejector design.

GEOMetric approximation for the ejector.

XO	YO		
0009.36000,	0001.25000		
X1	Y1	NX1	NY1
0000.10801,	0000.10801,	00012,	00003
X2	Y2		
0000.78000,	0000.34700		
X3	Y3		
0009.36000,	0001.04100		
X4	Y4		
0009.36000,	0001.87500		
Z1	NZ		
0000.90000,	00005		

COEFFicients for solution execution.

1TYPE	BETA	CSIGMA
00001,	0001.0550,	0000.30000

FREE stream fluid conditions.

TINF	PINF	GAMMA	RBAR	UNIF	ALPHA
0542.80000,	2067.84000,	0001.40000,	1714.54130,	0000.00000,	0090.00000

PRIMary nozzle discharge conditions.

SPECify states at each time step.

T	MDOT1P	T1P0	P1P
0000.00010,	0018.70000,	0769.70000,	2219.78000
0000.00020,	0018.70000,	0769.70000,	2219.78000
0000.00030,	0018.70000,	0769.70000,	2219.78000
0000.00040,	0018.70000,	0769.70000,	2219.78000
0000.00050,	0018.70000,	0769.70000,	2219.78000
0000.00060,	0021.85000,	0760.60000,	2250.92000
0000.00070,	0021.85000,	0760.60000,	2250.92000
0000.00080,	0021.85000,	0760.60000,	2250.92000
0			

C-----

## APPENDIX A - CODE SAMPLES

ARIEL\$ RUN TEA

\$\$\$ TEA FATAL ERROR # 6, \$\$\$  
%MTH-F-SQURONEG, square root of negative value  
user PC 000242C1  
%TRACE-F-TRACEBACK, symbolic stack dump follows  
module name      routine name      line

SPC	SPC	396
MEC	MEC	38
TEA	TEA	16
ARIEL\$		

ARIEL\$ RUN TEA

\$\$\$ TEA FATAL ERROR # 2, \$\$\$

\*\*\* ERROR DURING CALCULATIONS FOR T = 0.00040

DKE	=	976309.563
DKEOLD	=	2096179.500
SIGMA	=	71.929
PLOSS	=	11389.766
ENERGY1S	=	1076481.875
CHANGE	=	-1119870.000
VSTAR	=	-1261377.625

\*\*\* PROCEED W/ CHANGE = -0.999ENERGY1S

\*\*\* NEW VSTAR IS = 31295.961

FORTRAN STOP  
ARIEL\$

APPENDIX B - TEA PROGAM LISTING

```
00001 C TEA.FOR: Transient Ejector Analysis - Ver.2.1           15-AUG-91
00002 C=====
00003 C                                         Revised: 15-Feb-93
00004 C Colin K. Drummond
00005 C Propulsion Systems Division
00006 C NASA Lewis Research Center
00007 C Ref: "A Control-Volume Method for Analysis of Unsteady Thrust
00008 C     Augmenting Ejector Flows," NASA CR-182203.
00009 C=====
00010      PROGRAM TEA
00011 C
00012      OPEN (UNIT= 5, FILE= 'TEA.DAT',STATUS= 'OLD') ! Input data file
00013      OPEN (UNIT= 6, FILE= 'TEA.OUT',STATUS= 'NEW') ! Output data file
00014      OPEN (UNIT=10, FILE= 'TEA.PLT', STATUS= 'NEW') ! Plot data file
00015      CALL DIP          ! Data Input Processor
00016      CALL MEC          ! Main Execution Control
00017      CLOSE (UNIT= 5)
00018      CLOSE (UNIT= 6)
00019      CLOSE (UNIT=10)
00020      STOP
00021      END
```

## APPENDIX B - TEA PROGAM LISTING

```

00001 C=====
00002 C      SUBROUTINE DIP
00003 C
00004 C      Data Input Processor (DIP)
00005 C-----
00006      PARAMETER      (M=5000)
00007      CHARACTER*80   RUNID
00008      CHARACTER*4    TITLE(20)
00009      DIMENSION      T(M),DMPDT(M),T1PO(M),P1P(M)
00010      COMMON /CHECK/ ICHECK,INDEX
00011      COMMON /COEFX/ BETA,CSIGMA
00012      COMMON /ITYPE/ ITYPE
00013      COMMON /PLOTS/ IPLOT
00014      COMMON /LIST1/ X0,      Y0,
00015      &                  X1,      Y1,      NX1,      NY1,
00016      &                  X2,      Y2,
00017      &                  X3,      Y3,
00018      &                  X4,      Y4,
00019      &                  Z1,      NZ1,      DZ
00020      COMMON /LIST2/ GAMMA,   RBAR,     TINF,     PINF,     PBACK
00021      COMMON /LIST3/ ALPHA,   UINF
00022      COMMON /FLOW1/ ISW,     N,        T,        DMPDT,   T1PO,   P1P
00023      COMMON /FLOW2/ Z1TIME, Z1DMDT, Z1T1PO, Z1P1P, TSTEP
00024 C
00025 C.....DEFAULT DATA
00026      ALPHA = 90.00 ! Angle of attack of aircraft
00027      GAMMA = 1.40 ! Specific heat ratio
00028      ICHECK = 100 ! Print detailed time step output
00029      INDEX = 1    ! Print every I=1 times
00030      IPLOT = 0    ! No plotted output
00031      ITYPE = 1    ! Full transient solution (= 0, steady-state)
00032      PINF = 2067.84 ! Free-stream pressure, lbf/ft2 (14.7 psia)
00033      PBACK = PINF
00034      RBAR = 1714.54 ! Gas constant for AIR, ft2/s2R
00035      RUNID = 'TEA' ! Default RUNID
00036      TINF = 542.80 ! Free-stream temperature, R (70degF)
00037      UINF = 0.0   ! Free-stream velocity, ft/s (stationary ejector)
00038 C
00039 C.....READ INPUT DECK
00040      10 READ (5,'(20A4)',END=200) TITLE
00041      IF (TITLE(1).EQ.'BACK') GO TO 100
00042      IF (TITLE(1).EQ.'CASE') GO TO 110
00043      IF (TITLE(1).EQ.'COEF') GO TO 120
00044      IF (TITLE(1).EQ.'DISP') GO TO 130
00045      IF (TITLE(1).EQ.'FREE') GO TO 140
00046      IF (TITLE(1).EQ.'GEOM') GO TO 150
00047      IF (TITLE(1).EQ.'PRIM') GO TO 160
00048      IF (TITLE(1).EQ.'STOP') GO TO 200
00049      GO TO 10
00050 C
00051 C.....BACK pressure path to read PBACK specification.
00052 C      *** Note: This is ONLY needed if PBACK.NE.PINF
00053      100 READ (5,*) PBACK
00054      GO TO 10
00055 C
00056 C.....CASE path to read RUNID banner.
00057      110 READ (5,'(A)') RUNID

```

## APPENDIX B - TEA PROGAM LISTING

```

00058      GO TO 10
00059      C
00060      C.....COEFFicients path to read solution limits and coefficients
00061      120 READ (5,*)
00062          READ (5,*) ITYPE,BETA,CSIGMA
00063          GO TO 10
00064      C
00065      C.....DISPlay path for printout and plotting options.
00066      130 READ (5,*)
00067          READ (5,*) ICHECK,INDEX,IPLOT
00068          GO TO 10
00069      C
00070      C.....FREE stream path to read flow properties.
00071      140 READ (5,*)
00072          READ (5,*) TINF,PINF,GAMMA,RBAR,UINF,ALPHA
00073          PBACK = PINF
00074          GO TO 10
00075      C
00076      C.....GEOmetry path to read baseline ejector geometry.
00077      150 READ (5,*)
00078          READ (5,*) X0,Y0
00079          READ (5,*)
00080          READ (5,*) X1,Y1,NX1,NY1
00081          READ (5,*)
00082          READ (5,*) X2,Y2
00083          READ (5,*)
00084          READ (5,*) X3,Y3
00085          READ (5,*)
00086          READ (5,*) X4,Y4
00087          READ (5,*)
00088          READ (5,*) Z1,NZ1
00089          GO TO 10
00090      C
00091      C.....PRIMary path for specification of primary nozzle state.
00092      160 READ (5,'(20A4)') TITLE
00093          IF(TITLE(1).EQ.'SPEC') GO TO 161
00094          IF(TITLE(1).EQ.'STEP') GO TO 164
00095      C      --- Read step-by-step nozzle condition matrix ---
00096      161 ISW = 0
00097          READ (5,*)
00098          DO 162 I=1,M
00099          READ (5,*,ERR=163) T(I),DMPDT(I),T1PO(I),P1P(I)
00100      162 CONTINUE
00101      163 N = I-1
00102          K = N
00103          GO TO 10
00104      C      --- Read parameters for generating a step function ---
00105      164 ISW = 1
00106          READ (5,*)
00107          READ (5,*) T(1),DMPDT(1),T1PO(1),P1P(1)
00108          READ (5,*) Z1TIME, Z1DMDT, Z1TIPO, Z1P1P
00109          READ (5,*)
00110          READ (5,*) TSTEP,N
00111          K = 1
00112          GO TO 10
00113      C
00114      C.....STOP reading data and print data summary (if ICHECK.GE.50)

```

APPENDIX B - TEA PROGAM LISTING

```

00115 200 IF (ICHECK.LT.50) GO TO 999
00116      WRITE (6,700) RUNID,ICHECK,X0,Y0,X1,Y1,NX1,NY1,X2,Y2,
00117      &           X3,Y3,X4,Y4,Z1,NZ1,BETA,CSIGMA,TINF,PINF,
00118      &           GAMMA,RBAR,UINF,ALPHA,PBACK
00119      IF (ISW.EQ.0) THEN
00120          WRITE (6,706)
00121          WRITE (6,'((7X,I3,4(2X,F10.5))))')
00122          & ((I,T(I),DMPDT(I),T1P0(I),P1P(I)),I=1,K)
00123      ENDIF
00124      IF (ISW.EQ.1)
00125          & WRITE (6,705) T(1),DMPDT(1),T1P0(1),P1P(1),
00126          & Z1TIME,Z1DMDT,Z1T1P0,Z1P1P,TSTEP
00127          WRITE (6,703) N
00128          IF (ITYPE.EQ.0) WRITE (6,704)
00129          GO TO 999
00130 C......
00131 700 FORMAT(//,20X,'***** TEA INPUT *****',//3X,A,
00132      & //,5X,'CHECK PRINT LEVEL IS ',I3,
00133      & //,5X,'EJECTOR GEOMETRIC CHARACTERISTICS,'
00134      & //,7X,'X0 = ',F10.5,5X,'Y0 = ',F10.5,
00135      & //,7X,'X1 = ',F10.5,5X,'Y1 = ',F10.5,
00136      & //,7X,'NX1= ',I5,10X,'NY1= ',I5,
00137      & //,7X,'X2 = ',F10.5,5X,'Y2 = ',F10.5,
00138      & //,7X,'X3 = ',F10.5,5X,'Y3 = ',F10.5,
00139      & //,7X,'X4 = ',F10.5,5X,'Y4 = ',F10.5,
00140      & //,7X,'Z1 = ',F10.5,5X,'NZ = ',I5,5X,
00141      & //,5X,'MIXING LOSS CORRECTION FACTOR',
00142      & //,7X,'BETA = ',F10.5,
00143      & //,5X,'KINETIC ENERGY MIXING COEFFICIENT',
00144      & //,7X,'CSIGMA = ',F10.5
00145      & //,5X,'FREE-STREAM THERMODYNAMIC PROPERTIES',
00146      & //,7X,'STATIC TEMPERATURE = ',F10.5,' DEG-RANKINE',
00147      & //,7X,'STATIC PRESSURE = ',F10.5,' LB-F/FT3',
00148      & //,7X,'SPECIFIC HEAT RATIO = ',F10.5,
00149      & //,7X,'GAS CONSTANT, AIR = ',F10.5,' FT2/S2-R',
00150      & //,7X,'FREESTREAM VELOCITY = ',F10.5,' FT/S',
00151      & //,7X,'ANGLE-OF-ATTACK = ',F10.5,' DEGREES',
00152      & //,5X,'EJE BACK PRESSURE IS ',F10.5,' LBF/FT2',
00153      & //,5X,'PRIMARY NOZZLE DATA',//)
00154 703 FORMAT(//5X,'PROGRAM WILL OPERATE ON ',I5,' DATA SETS')
00155 704 FORMAT(//5X,'QUASI-STEADY SOLUTION INVOKED')
00156 705 FORMAT( 7X,'STEP FUNCTION FOR PRIMARY NOZZLE DISCHARGE',
00157      & //,7X,' T ',4X,' DMPDT',7X,'T1P0 ',5X,' P1P',4X,
00158      & //,6X,'(sec)',4X,'(lbm/s)',5X,'(degR)',4X,'(lbf/ft2)',
00159      & //,4(2X,F10.5),/,4(2X,F10.5),//,9X,'TSTEP = ',F10.5)
00160 706 FORMAT(
00161      &7X,'DATA',7X,' T ',4X,' DMPDT',7X,'T1P0 ',5X,' P1P',4X,/,
00162      &7X,'SET#',6X,'(sec)',4X,'(lbm/s)',5X,'(degR)',4X,'(lbf/ft2)')
00163 999 RETURN
00164     END

```

APPENDIX B - TEA PROGAM LISTING

```

00001 C=====
00002      SUBROUTINE MEC
00003 C
00004      Main Execution Control (MEC) Routine
00005 C-----
00006 C
00007      PARAMETER (M=5000)
00008      COMMON /CHECK/ ICHECK,L
00009      COMMON /ITYPE/ ITYPE
00010      COMMON /PLOTS/ IPLOT
00011      COMMON /LAST1/ TLAST
00012      COMMON /FLOW1/ ISW,      N,      T,      DMPDT, T1PO,   P1P
00013      COMMON /FLOW2/ Z1TIME, Z1DMDT, Z1T1PO, Z1P1P, TSTEP
00014      DIMENSION T(M),DMPDT(M),T1PO(M),P1P(M),THRUST(M),PHI(M)
00015 C
00016 C---LOOP ON SPC ROUTINE FOR SPECIFIED PRIMARY FLOW DRIVER
00017      MODE = 0
00018      TLAST = T(1)
00019      DO 20 I=1,N
00020      IF (I.EQ.1) GO TO 20
00021      MODE = 1
00022      TLAST = T(I-1)
00023      IF (ISW.EQ.1) GO TO 5
00024      TSTEP = T(I)-T(I-1)
00025      GO TO 15
00026 C      --- STEP FUNCTION OPERATION ---
00027      5      T(I) = T(I-1) + TSTEP
00028      IF (T(I).GE.Z1TIME) GO TO 6
00029      T1PO(I) = T1PO(1)
00030      P1P(I) = P1P(1)
00031      DMPDT(I) = DMPDT(1)
00032      GO TO 15
00033      6      T1PO(I) = Z1T1PO
00034      P1P(I) = Z1P1P
00035      DMPDT(I) = Z1DMDT
00036      GO TO 15
00037      15     IF (ITYPE.EQ.0) MODE=0
00038      20 CALL SPC(T(I),DMPDT(I),T1PO(I),P1P(I),THRUST(I),PHI(I),MODE)
00039 C
00040 C---PRINT TO TEXT AND PLOT FILES AS REQUESTED
00041      IF (ICHECK.GE.50) THEN
00042      WRITE(6,100)
00043      WRITE(6,'((2X,4(2X,F10.5))))')
00044      & (((T(I)*1000.0),DMPDT(I),THRUST(I),PHI(I)),I=1,N,L)
00045      ENDIF
00046      IF (IPLOT.GT.0) THEN
00047      WRITE(10,109)
00048      WRITE(10,'((2X,4(2X,F10.5))))')
00049      & (((T(I)*1000.0),DMPDT(I),THRUST(I),PHI(I)),I=1,N,IPLOT)
00050      ENDIF
00051 C
00052      100 FORMAT(1H1/,14X,5(1H*),' SOLUTION PROFILE ',5(1H*),
00053      & //7X,'    T    ',4X,' DMpDT ',6X,'THRUST',8X,'PHI',
00054      & /7X,'(m-sec)',4X,'(1bm/s)',6X,' (1b)',/)
00055      109 FORMAT(7X,'    T    ',4X,' DMpDT ',6X,'THRUST',8X,'PHI')
00056      199 RETURN
00057      END

```

## APPENDIX B - TEA PROGAM LISTING

```

00001 C=====
00002      SUBROUTINE SPC(T,DMPDT,T1P0,P1P,THRUST,PHI,MODE)
00003 C
00004      Single Point Calculation (SPC) Routine
00005 C-----
00006 C
00007      COMMON /CHECK/ ICHECK, INDEX
00008      COMMON /COEFX/ BETA, CSIGMA
00009      COMMON /LAST1/ TLAST
00010      COMMON /LIST1/ XO, YO,
00011      & X1, Y1, NX1, NY1,
00012      & X2, Y2,
00013      & X3, Y3,
00014      & X4, Y4,
00015      & Z1, NZ1, DZ
00016      COMMON /LIST2/ GAMMA, RBAR, TINF, PINF, PBACK
00017      COMMON /LIST3/ ALPHA, U
00018      COMMON /LIST4/ E, F, G
00019      COMMON /LIST5/ P1S, T1S, V1S, D1S, Z1S
00020      COMMON /LIST6/ PE, TE, VE, RE
00021      COMMON /LIST7/ PM, TM, VM, RM
00022      COMMON /LIST8/ DRDT, DEDT, DKEOLD, VENEW, DVE
00023 C
00024      DIMENSION B(50), BSTAR(50), E(15,50), F(15,50),
00025      & G(15,50), PE(50), PM(50), RE(50), RM(50),
00026      & TE(50), TM(50), VE(50), VM(50), XIHAT(50), Z(50),
00027      & BI(50), BII(50), DRDT(50), DPDT(50), DEDT(50), DVDT(50)
00028      REAL*8 V1P,V1S,R2,THETA1,DZ,B,BI,BII,THETA2,XIHAT
00029      REAL*8 SURGE,DELTA,DM3DT,DM4DT,D1S,D1P,A1S,A1PT
00030      REAL*8 T1S,C1S,PE,PM,VE,VM,RE,RM,DMSDT
00031      REAL*8 BVALUE,CVALUE,B24AC,C8
00032      REAL*8 DM1DT,FLUXP,FLUXM,FLUXMI,FLUXMJ
00033 C
00034 C---INTERNAL FUNCTION DEFINITIONS
00035 C
00036      CP(G,R) = R*G/(G-1.0)
00037      F2(G,Z) = 1.0 + 0.5*(G-1.0)*Z*Z
00038      F3(G,Z) = F2(G,Z)**(G/(G-1.0))
00039      FZ0(PM,PE,E1,E2) = PM*E1 + PE*E2
00040      FZ1(RM,RE,VM,VE,C1,C2,C3,C4) =
00041      & RM*VM*C1 + RE*VM*C2 + RM*VE*C3 + RE*VE*C4
00042      FZ2(RM,RE,VM,VE,G1,G2,G3,G4,G5,G6) =
00043      & RM*G1*VM*VM + RM*G2*VE*VE + RM*G3*VE*VM +
00044      & RE*G4*VM*VM + RE*G5*VE*VE + RE*G6*VE*VM
00045      FZETA(Z,C1,C2,C3,C4) = C1*Z**4. + C2*Z**2.5 + C3*Z + C4
00046      FPZETA(Z,C1,C2,C3) = 4.*C1*Z**3. + 2.5*C2*Z**1.5 + C3
00047      FPPZETA(Z,C1,C2) = 12.*C1*Z**2. + 3.75*C2*Z**0.5
00048      GFT(T)=1.3825+0.10173*T*(1.-1.5638*T*(1.0-.4016*T*(1.-.1304*T)))
00049      H1G(Z) = (4531. + 1309.*Z**10. - 9240.*Z**8.5 + 22440.*Z**7.
00050      & -19040.*Z**5.5)/13090.0
00051      H2G(Z) = (729. + 1122.*Z**10. - 7920.*Z**8.5 + 22440.*Z**7.
00052      & -32640.*Z**5.5 + 25245.*Z**4. - 8976.*Z**2.5)/3740.0
00053      H3G(Z) = (2727. - 3927.*Z**10. + 27720.*Z**8.5 - 72930.*Z**7.
00054      & +85680.*Z**5.5 - 39270.*Z**4.)/13090.0
00055      H4G(Z) = ( 6561. - 2618.*Z**10. + 18480.*Z**8.5 - 56100.*Z**7.
00056      & +95200.*Z**5.5 - 98175.*Z**4. + 62832.*Z**2.5
00057      & -26180.*Z)/26180.0

```

## APPENDIX B - TEA PROGAM LISTING

```

00058      H1L(Z) = -(H1G(Z) - 4531.0/13090.0)
00059      H2L(Z) = -(H2G(Z) - 729.0/ 3740.0)
00060      H3L(Z) = -(H3G(Z) - 2727.0/13090.0)
00061      H4L(Z) = -(H4G(Z) - 6561.0/26180.0)
00062      C
00063      C---GLOBAL PARAMETER INITIALIZATION
00064      C
00065          ITN   = 0
00066          LIMIT = 50
00067          GC    = 32.174
00068          W     = Y2
00069          SCALE = FLOAT(NX1)*FLOAT(NY1)
00070          N     = NZ1+1
00071          DZ    = Z1/FLOAT(NZ1)
00072      C
00073      C---CONDITIONS FOR FREE-STREAM
00074      C
00075          10 ALPHAR = ALPHA*3.1415/180.0
00076          VINF  = U*SIN(ALPHAR)
00077          DUyDT = DUDT*SIN(ALPHAR)
00078          DINF  = PINF/(RBAR*TINF/GC)
00079          POINF = PINF+0.5*VINF*VINF*DINF/GC
00080          TOINF = TINF+0.5*VINF*VINF/CP(GAMMA,RBAR)
00081          AINF  = X0*Y0
00082          DMIDT = AINF*VINF*DINF
00083      C
00084      C---EVALUATE PRIMARY NOZZLE CONDITIONS
00085      C
00086          A1P  = X1*Y1
00087          A1PT= A1P*FLOAT(NX1)*FLOAT(NY1)
00088          ZZ0  = GAMMA/(GAMMA-1.0)
00089          ZZ1  = (GAMMA-1.0)/GAMMA
00090          ZZ2  = (GAMMA+1.0)/2.0
00091          ZZ3  = 2.0*GAMMA*(GAMMA+1.0)
00092          ZZ4  = (DMPDT/(A1PT*PBACK*GC))**2.0
00093          ZZ4  = ZZ4*T1P0*RBAR*(GAMMA-1.0)/(2.0*GAMMA)
00094          PRN  = (0.5+0.5*SQRT(1.0+4.0*ZZ4))**ZZ0
00095          XPRN= ZZ2**ZZ0
00096      C
00097      C     CHECK FOR CHOKED FLOW....
00098          IF (PRN.LT.XPRN) GO TO 17
00099      C
00100      C     CHOKED NOZZLE FLOW OPERATIONS...
00101          P1P0  = 1.88076*(DMPDT/A1PT)*SQRT(T1P0)
00102          PRN  = P1P0/PBACK
00103          Z1P  = 1.0
00104          P1P  = P1P0/F3(GAMMA,Z1P)
00105          YPRN = P1P0/P1P
00106          FORCE1P= DMPDT*(2.0/GC)*SQRT((T1P0*RBAR)/ZZ3)
00107          FORCE1P= FORCE1P*(GAMMA + 1.0 - XPRN/PRN)
00108          GO TO 19
00109
00110      C     SUBSONIC NOZZLE COMPUTATIONS...
00111          17   ZZ4   = (DMPDT/(A1PT*P1P*GC))**2.0
00112          ZZ4   = ZZ4*T1P0*RBAR*(GAMMA-1.0)/(2.0*GAMMA)
00113          YPRN = (0.5+0.5*SQRT(1.0+4.0*ZZ4))**ZZ0
00114          Z1P   = SQRT((2.0/(GAMMA-1.0))*(YPRN**ZZ1 - 1.0))

```

APPENDIX B - TEA PROGAM LISTING

```

00115      P1PO = P1P*YPRN
00116      PRN = P1PO/PBACK
00117      PRN = AMAX1(1.,PRN)
00118      FORCE1P= DMPDT*(SQRT(T1PO))/GC
00119      FORCE1P= FORCE1P*SQRT((2.*RBAR*ZZ0)*(1.0-(1./PRN)**ZZ1))
00120 19 CONTINUE
00121      T1P = T1PO/F2(GAMMA,Z1P)
00122      D1P = P1P/(T1P*RBAR/GC)
00123      C1P = SQRT(GAMMA*RBAR*T1P)
00124      V1P = Z1P*C1P
00125      DMPDT = D1P*V1P*A1PT
00126  C
00127  C---PREDICT SECONDARY FLOW PROPERTIES
00128  C
00129      A1S = (X3*Y3)-A1PT
00130      P1S0=POINF
00131      T1S0=T0INF
00132  C   STATION 1-S INITIAL VELOCITY ESTIMATE
00133      IF (MODE.EQ.0) V1S = 1.0
00134      IF (MODE.EQ.1) V1S = VENEW
00135  C   ITERATE ON ACTUAL SOLUTION
00136  20 ITN = ITN + 1
00137      T1S = T1S0 - 0.5*(V1S**2.0)/CP(GAMMA,RBAR)
00138      P1S = P1S0*(T1S/T1S0)**(GAMMA/(GAMMA-1.0))
00139      D1S = P1S/(RBAR*T1S/GC)
00140      DMSDT = D1S*V1S*A1S
00141      ER = DMSDT/DMPDT
00142      ENERGY1S = 0.5*D1S*V1S**3.0
00143  C
00144  C---MIXING REGION PREDICTIONS
00145  C
00146      AREA3 = X3*Y3
00147      DM1DT = DMPDT + DMSDT
00148      PM(1) = P1P
00149      PE(1) = P1S
00150      RM(1) = D1P/GC
00151      RE(1) = D1S/GC
00152      VM(1) = V1P
00153      VE(1) = V1S
00154  C
00155  C--- VIRTUAL GRID INITIALIZATION
00156  C
00157      R2 = V1S/V1P
00158      THETA1 = DATAN(0.4*(1-R2)*(0.416+0.134*R2)/(1+R2))
00159      BI(1) = A1P/(W*2.0)
00160      BI(2) = BI(1) - DZ*DTAN(THETA1)
00161      IF(BI(2).LE.0.0) BI(2)=0.0
00162      BII(1) = BI(1)
00163      BMAX = X2/2.0
00164  C
00165  C   COMPUTE OUTER JET EXPANSION ANGLE
00166      C1 = BI(2)*D1P*V1P + (BMAX-BI(2))*D1S*V1S
00167      C2 = 0.45*D1P*V1P + 0.55*D1P*V1S - D1S*V1S
00168      B(2) = ((DM1DT/(2.0*SCALE*W))-C1)/C2
00169      BII(2)= B(2)+BI(2)
00170      THETA2= DATAN ((BII(2)-BII(1))/DZ)
00171  C

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## APPENDIX B - TEA PROGAM LISTING

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00172 C COMPUTE FINAL GRID BOUNDARIES
00173 DO 34 I = 2,N
00174     Z(I) = DZ*FLOAT(I-1)
00175     BI(I) = BI(1) - Z(I)*DTAN(THETA1)
00176     IF(BI(I).LE.0.0) BI(I)=0.0
00177     BII(I) = BII(1) + Z(I)*DTAN(THETA2)
00178     IF(BII(I).GT.BMAX) BII(I)=BMAX
00179     B(I) = BII(I) - BI(I)
00180     XIHAT(I) = (BMAX-BI(I))/B(I)
00181 34 CONTINUE
00182 C
00183 C COMPUTE SIGMA
00184 C     SIGMA = CSIGMA*Z(N)*144.0/(1.0+Z1P)
00185 C     SIGMA = CSIGMA*((1.0+0.23*Z1P)*12.0/Z(N))**2.0
00186 C
00187 C COMPUTE SELF-SIMILAR PROFILE INTEGRALS FOR THE NEW JET
00188 DO 37 I=2,N
00189     BIB = BI(I)/B(I)
00190     E(I,1) = BIB + 1.00
00191     E(I,2) = XIHAT(I) - 1.00
00192     F(I,1) = BIB + 0.45
00193     F(I,2) = 0.0
00194     F(I,3) = 0.55
00195     F(I,4) = XIHAT(I) - 1.0
00196     G(I,1) = (BIB + 243.0/770.0)
00197     G(I,2) = (320.0/770.0)
00198     G(I,3) = (414.0/1540.0)
00199     G(I,4) = 0.0
00200     G(I,5) = (XIHAT(I) - 1.0)
00201     G(I,6) = 0.0
00202 37 CONTINUE
00203 INCLUDE 'XCHECK1.FOR'
00231 C
00232 C---SKIP FINITE VOLUME INITIALIZATION IF MODE > 0
00233 C
00234 IF (MODE.EQ.1) GO TO 40
00235 C
00236 C---INITIALIZATION OF FIELD VARIABLES
00237 C
00238 DO 39 I = 1,N-1
00239     J = I+1
00240     RE(J) = RE(I)
00241     PE(J) = PE(I)
00242     DO 38 K=1,3
00243         VE(J) = VE(I)
00244         C8 = 0.5*VE(I)*VE(I)
00245         & + GAMMA/(GC*(GAMMA-1.0))*(PE(I)/RE(I)-PE(J)/RE(J))
00246         IF(C8.GT.0.0) VE(J) = SQRT(2*C8)
00247         IF (I.EQ.1) THEN
00248             FLUXRI = RM(I)*VM(I)*A1PT + RE(I)*VE(I)*A1S
00249             FLUXPI = PM(I)*VM(I)*A1PT + PE(I)*VE(I)*A1S
00250             FLUXMI = (PM(I)+RM(I)*VM(I)*VM(I))*A1PT
00251             & + (PE(I)+RE(I)*VE(I)*VE(I))*A1S
00252         ELSE
00253             FLUXRI = 2.0*SCALE*W*B(I)*
00254             & FZ1(RM(I),RE(I),VM(I),VE(I),F(I,1),F(I,2),F(I,3),F(I,4))
00255             FLUXPI = 2.0*SCALE*W*B(I)*

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## APPENDIX B - TEA PROGAM LISTING

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00256    &      FZ1(PM(I),PE(I),VM(I),VE(I),F(I,1),F(I,2),F(I,3),F(I,4))
00257    &      FLUXMI = 2.0*SCALE*W*B(I)*(
00258    &      FZ2(RM(I),RE(I),VM(I),VE(I),G(I,1),G(I,2),G(I,3),G(I,4),
00259    &                      G(I,5),G(I,6))
00260    &      +FZ0(PM(I),PE(I),E(I,1),E(I,2)))
00261    ENDIF
00262    C1 = (G(J,3)+G(J,6))/(G(J,1)+G(J,4))
00263    C2 = (F(J,1)+F(J,2))/(G(J,1)+G(J,4))
00264    C3 = (G(J,2)+G(J,5))/(G(J,1)+G(J,4))
00265    C4 = (E(J,1)+E(J,2))/(G(J,1)+G(J,4))
00266    C5 = (F(J,3)+F(J,4))/(G(J,1)+G(J,4))
00267    BVALUE= VE(J)*C1 - (FLUXMI/FLUXRI)*C2
00268    CVALUE= VE(J)*VE(J)*C3 + (FLUXPI/FLUXRI)*C4
00269    &          - VE(J)*(FLUXMI/FLUXRI)*C5
00270    B24AC = (BVALUE**2.0) - 4.0*CVALUE
00271    IF (B24AC.LT.0.0) THEN
00272        WRITE(*,900) 1
00273        INCLUDE 'XCHECK2.FOR'
00295    ENDIF
00296    VM(J) = -0.5*(BVALUE+DSQRT(B24AC))
00297    C6 = FLUXRI/(2.0*SCALE*W*B(J)*(F(J,1)+F(J,2)))
00298    C7 = VE(J)*(F(J,3)+F(J,4))/(F(J,1)+F(J,2))
00299    C8 = FLUXPI/(2.0*SCALE*W*B(J)*(F(J,1)+F(J,2)))
00300    RM(J) = C6/(VM(J)+C7)
00301    RE(J) = RM(J)
00302    PM(J) = C8/(VM(J)+C7)
00303    PE(J) = PM(J)
00304    38 CONTINUE
00305    39 CONTINUE
00306    C
00307    C---DERIVATIVE ESTIMATES
00308    C
00309    40 DT    = T-TLAST
00310    C
00311    C ...SKIP DERIVATIVE COMPUTATIONS IF DT=0
00312    IF(DT.LE.0.0) GO TO 43
00313    C
00314    C ...NO DERIVATIVES ARE NEEDED FOR QUASI-STEADY FLOW
00315    IF(MODE.EQ.0) GO TO 43
00316    C
00317    C ...PROCEED WITH DERIVATIVE COMPUTATIONS
00318    DO 42 I = 1,N-1
00319        J = I+1
00320    C
00321    C     ...UPDATE ENTRAINED VELOCITY
00322        VE(J) = VE(I)
00323        C8 = 0.5*VE(I)*VE(I)
00324        &      + GAMMA/(GC*(GAMMA-1.0))*(PE(I)/RE(I)-PE(J)/RE(J))
00325        IF(C8.GT.0.0) VE(J) = SQRT(2.0*C8)
00326
00327    C
00328    C     ...COMPUTE STATION 'I' FLUXES
00329        IF (I.EQ.1) THEN
00330            FLUXRI = DM1DT/(2.0*SCALE*W*GC)
00331            FLUXMI = ((A1PT*(P1P+D1P*V1P*V1P/GC))
00332            &          +(A1S*(P1S+D1S*V1S*V1S/GC)))/(2.0*SCALE*W)
00333            FLUXPI = ((A1PT*P1P*V1P)+(A1S*P1S*V1S))/(2.0*SCALE*W)

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## APPENDIX B - TEA PROGAM LISTING

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00334      ELSE
00335      &   FLUXRI = B(I)*FZ1(RM(I),RE(I),VM(I),VE(I),
00336          &           F(I,1),F(I,2),F(I,3),F(I,4))
00337      &   FLUXMI = B(I)*(FZ2(RM(I),RE(I),VM(I),VE(I),
00338          &           G(I,1),G(I,2),G(I,3),G(I,4),
00339          &           G(I,5),G(I,6))
00340      &   +FZO(PM(I),PE(I),E(I,1),E(I,2)))
00341      &   FLUXPI = B(I)*FZ1(PM(I),PE(I),VM(I),VE(I),
00342          &           F(I,1),F(I,2),F(I,3),F(I,4))
00343      ENDIF
00344 C
00345 C ... COMPUTE STATION 'J' FLUXES ...
00346      &   FLUXRJ = B(J)*FZ1(RM(J),RE(J),VM(J),VE(J),
00347          &           F(J,1),F(J,2),F(J,3),F(J,4))
00348      &   FLUXMJ = B(J)*(FZ2(RM(J),RE(J),VM(J),VE(J),
00349          &           G(J,1),G(J,2),G(J,3),G(J,4),
00350          &           G(J,5),G(J,6))
00351      &   +FZO(PM(J),PE(J),E(J,1),E(J,2)))
00352      &   FLUXPJ = B(J)*FZ1(PM(J),PE(J),VM(J),VE(J),
00353          &           F(J,1),F(J,2),F(J,3),F(J,4))
00354 C
00355 C ... COMPUTE PRIMARY FLOW DERIVATIVES ...
00356      DEDT(I) = DVE/DT
00357      DRDT(I) = (FLUXRI - FLUXRJ)/(BMAX*DZ)
00358      DPDT(I) = (FLUXPI - FLUXPJ)/(BMAX*DZ)
00359      CDVDT = 0.0
00360      C1 = (F(J,3)+F(J,4))/(F(J,1)+F(J,2))
00361      C2 = C1*DEDT(I)*CDVDT - (DRDT(I)/RM(J))*(VM(J)+VE(J)*C1)
00362      DVDT(I) = (FLUXMI - FLUXMJ)/(B(J)*DZ) - C2
00363 C
00364 C ... ADVANCE PRIMARY FLOW FORWARD IN TIME ...
00365      RM(J) = RM(J) + DRDT(I)*DT
00366      RE(J) = RM(J)
00367      PM(J) = PM(J) + DPDT(I)*DT
00368      PE(J) = PM(J)
00369      VM(J) = VM(J) + DVDT(I)*DT
00370 42 CONTINUE
00371 C
00372 C COMPUTE THE JET STREAMLINE
00373 43 DO 45 J = 2,N
00374      ISTOP= 0
00375      ZETA = BI(1)/B(J)
00376      C1 = 0.25*(VM(J)-VE(J))
00377      C2 = 0.80*(VE(J)-VM(J))
00378      C3 = VM(J)
00379      C4 = (RE(1)/RE(J))*((BMAX-BI(1))/B(J))*V1S
00380      &           - C1 - C2 - C3 - ((BMAX/B(J)) - 1.)*VE(J)
00381      44 ISTOP = ISTOP + 1
00382      C5 = FZETA(ZETA,C1,C2,C3,C4)/FPZETA(ZETA,C1,C2,C3)
00383      C6 = 1- FZETA(ZETA,C1,C2,C3,C4)*FPPZETA(ZETA,C1,C2)
00384      &           /FPZETA(ZETA,C1,C2,C3)**2.0
00385      DELTA = -C5/C6
00386      ZETA = ZETA + DELTA
00387      BSNEW = ZETA*B(J)
00388      IF (BSNEW.GE.BMAX) THEN
00389          BSTAR(J) = BMAX
00390          GO TO 45

```

## APPENDIX B - TEA PROGAM LISTING

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00391      ENDIF
00392      IF((ABS(DELTA).GE.0.000001).AND.(ISTOP.LT.50)) GO TO 44
00393      BSTAR(J) = BSNEW
00394 45 CONTINUE
00395 C
00396 C---KINETIC ENERGY EXCHANGE
00397 C
00398      ZETA = BSTAR(N)/B(N)
00399      ZSTAR = BMAX/B(N)
00400      C1 = (H1G(ZETA) - (0.55 + 0.25*ZETA**4.-0.8*ZETA**2.5))
00401      & *VE(N)**3.0
00402      C2 = (H3G(ZETA) - (0.45-(0.25*ZETA**4.-0.8*ZETA**2.5+ZETA)))
00403      & *VM(N)*VE(N)**2.0
00404      C3 = H2G(ZETA)*VE(N)*VM(N)**2.0
00405      C4 = H4G(ZETA)*VM(N)**3.0
00406      DKE = B(N)*RM(N)*GC*(C1+C2+C3+C4)
00407      C1 = H1L(ZETA)*VE(N)**3. + H2L(ZETA)*VE(N)*VM(N)**2.
00408      & + H3L(ZETA)*VM(N)*VE(N)**2. + H4L(ZETA)*VM(N)**3.
00409      C2 = (0.25*ZETA**4. - 0.8*ZETA**2.5 + ZETA)*VM(N)**3.
00410      & + (-0.25*ZETA**4. + 0.8*ZETA**2.5)*VE(N)*VM(N)**2.
00411      PLOSS = -B(N)*RM(N)*GC*(C1-C2)
00412      DKE = DKE + SIGMA*PLOSS
00413      CHANGE = DKE - DKEOLD
00414      VSTAR = ((ENERGY1S+CHANGE)/(0.5*D1S))
00415      IF(VSTAR.LT.0.0) THEN
00416          WRITE(*,900) 2
00417          INCLUDE 'XCHECK3.FOR'
00418      ENDIF
00419      VENEW = (ABS(VSTAR))**1./3.)
00420      DVE = VENEW-V1S
00421      DKEOLD = DKE
00422 C
00423 C---ASSIGN MIXING REGION EXIT CONDITIONS
00424 C
00425      ZZZ = (2.0*SCALE*W*B(N))/AREA3
00426      V3 = ZZZ*(0.45*VM(N) + (XIHAT(N)-0.45)*VE(N))
00427      D3 = RM(N)*GC
00428      IF (D3.LT.0.0) WRITE(*,900) 3
00429      IF (D3.GE.1.0) WRITE(*,900) 4
00430      P3 = PM(N)
00431      T3 = P3/(RBAR*D3/GC)
00432      IF (T3.LT.0.0) WRITE(*,900) 5
00433      C3 = SQRT(GAMMA*RBAR*T3)
00434      Z3 = V3/C3
00435      P30 = P3*F3(GAMMA,Z3)
00436      T30 = T3*F2(GAMMA,Z3)
00437      DM3DT= D3*V3*AREA3
00438 C
00439 C---DIFFUSER PREDICTIONS
00440 C
00441      50 AREA4 = X4*Y4
00442      P40 = P30
00443      T40 = T30
00444      IF(MODE.EQ.0) THEN
00445          P4 = PBACK
00446          IF(P40.LT.P4) WRITE(*,900) 6
00447          Z4 = SQRT((2.0/(GAMMA-1.0)))

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## APPENDIX B - TEA PROGAM LISTING

```

00468      & *(((P40/P4)**((GAMMA-1.0)/GAMMA))-1.0))
00469      T4 = T40/F2(GAMMA,Z4)
00470      D4 = P4/(RBAR*T4/GC)
00471      C4 = SQRT(GAMMA*RBAR*T4)
00472      V4 = Z4*C4
00473      ELSE
00474          C1 = 0.5/(GAMMA-1.0)
00475          C2 = (GAMMA/(GAMMA-1.0))*GC*AREA4*P30/DM3DT
00476          C3 = CP(GAMMA, RBAR)*T30
00477          V4 = (C2-SQRT(C2*C2-4.0*C1*C3))/(2.0*C1)
00478          D4 = DM3DT/(V4*AREA4)
00479          P4 = P40 - 0.5*D4*V4*V4/GC
00480          T4 = T40 - 0.5*V4*V4/CP(GAMMA, RBAR)
00481          C4 = SQRT(GAMMA*RBAR*T4)
00482      ENDIF
00483      DM4DT = D4*V4*AREA4
00484
00485      C--- CHECK FOR CONTINUITY
00486      C
00487          EPSILON = 0.00005
00488          SURGE = (DM4DT - DM3DT)/(D1S*A1S)
00489          IF(MODE.EQ.1) GO TO 70
00490          IF (ABS(SURGE).LE.EPSILON) THEN
00491              GO TO 70
00492          ELSE
00493              V1S = V1S + SURGE
00494              INCLUDE 'XCHECK4.FOR'
00495              IF(ITN.LT.LIMIT) GO TO 20
00496          ENDIF
00497      C---THRUST AND THRUST AUGMENTATION RESULTS
00498      C
00499          70 THRUST = (DM4DT*(V4/(BETA**2.)-VINF)/(GC))
00500          &           + AREA4*(PBACk-PINF)
00501          PHI     = THRUST/FORCE1P
00502
00503      C---PRINT OPTION
00504      C
00505          IF(ICHECK.LT.100) GO TO 999
00506          WRITE (6,200) T
00507          WRITE (6,201) AINF, A1PT, A1S, AREA3, AREA4,
00508          &           VINF, V1P, V1S, V3, V4,
00509          &           PINF, P1P, P1S, P3, P4,
00510          &           POINF, P1PO, P1SO, P30, P40,
00511          &           TINF, T1P, T1S, T3, T4,
00512          &           TOINF, T1PO, T1SO, T30, T40,
00513          &           DINF, D1P, D1S, D3, D4,
00514          &           DMIDT, DMPDT, DMSDT, DM3DT, DM4DT
00515          WRITE (6,202) PRN, XPRN
00516          IF(MODE.EQ.0) WRITE (6,203) SURGE, ITN, LIMIT
00517          WRITE (6,204)
00518          WRITE (6,207)((I,Z(I),BI(I),BII(I),BSTAR(I)),I=2,N)
00519          WRITE (6,206)
00520          WRITE (6,207)((I,RM(I),PM(I),VM(I),VE(I)),I=1,N)
00521          WRITE (6,208)
00522          WRITE (6,207)((I,DRDT(I),DPDT(I),DVDT(I),DEDT(I)),I=1,N-1)
00523          WRITE (6,209) THETA1,THETA2,BI(1),BMAX
00524          WRITE (6,210) THRUST,FORCE1P,PHI

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## APPENDIX B - TEA PROGAM LISTING

```

00535 200 FORMAT(1H1,/,,19X,'***** SINGLE POINT CALCULATION *****',
00536 & /,,29X,'T = ',F8.5,' sec')
00537 201 FORMAT( /,,3X,'FIELD VARIABLE PROFILE:',/,
00538 & /,,3X,'Station -> Infinity',6X,'1P',10X,'1S',10X,
00539 & '3      4',/,
00540 & /,,3X,'AREA   ',2X,5(F10.5,2X),'FT',
00541 & /,,3X,'V     ',2X,5(F10.5,2X),'FT/S',
00542 & /,,3X,'P     ',2X,5(F10.5,2X),'LBF/FT2',
00543 & /,,3X,'PO    ',2X,5(F10.5,2X),'LBF/FT2',
00544 & /,,3X,'T     ',2X,5(F10.5,2X),'DEG-R',
00545 & /,,3X,'TO    ',2X,5(F10.5,2X),'DEG-R',
00546 & /,,3X,'RHO   ',2X,5(F10.5,2X),'LBM/FT3',
00547 & /,,3X,'MDOT  ',2X,5(F10.5,2X),'LBM/S')
00548 202 FORMAT(7X,'NOTES:',/10X,'Nozzle Pressure Ratio is ',F8.5,
00549 & ' (Choked NPR is ',F8.5,' )')
00550 203 FORMAT( 10X,'Station 3-4 SURGE error is ',F12.8,
00551 & /,,10X,'Solution obtained in ',I3,' iterations, limit is ',I3)
00552 204 FORMAT(/,,3X,'FINITE VOLUME PROFILE',//,,5X,'Station Z',
00553 & 10X,'B.inner',7X,'B.outer',8X,'B.js1 ')
00554 206 FORMAT(/,,5X,'Station',4X,'Rho',11X,'P',13X,'Vm',12X,'Ve')
00555 207 FORMAT(6X,I3,2X,E12.5,2X,E12.5,2X,E12.5,2X,E12.5)
00556 208 FORMAT(/,,5X,
00557 &'Element D(Rho)/DT      D(P)/DT      D(Vm)/DT      D(Ve)/DT')
00558 209 FORMAT(7X,'NOTES:',
00559 & /10X,'Inner jet expansion, Theta1 ',F8.5,' radians',
00560 & /10X,'Outer jet expansion, Theta2 ',F8.5,' radians',
00561 & /10X,'Initial jet with, B0, ',F8.5,' Ft',
00562 & /10X,'Allowable jet width, Bmax, ',F8.5,' Ft')
00563 210 FORMAT( /,,3X,'PREDICTED THRUST AND PERFORMANCE:',
00564 & //,,5X,'Total ejector thrust = ',F12.5,' Lb',
00565 & /,,5X,'Isentropic primary thrust = ',F12.5,' Lb',
00566 & /,,5X,'Thrust augmentation ratio = ',F12.5)
00567 900 FORMAT(/5X,'$$$ TEA FATAL ERROR # ',I2,', $$$/')
00568 999 RETURN
00569 END

```

APPENDIX B - TEA PROGAM LISTING

```
00001 C=====
00002 C      XCHECK1.FOR
00003 C-----
00004 C      PRINT MIXING REGION DATA FOR DEBUG CHECKS
00005 C-----
00006 1000 IF(ICHECK.LT.1000) GO TO 1020
00007      WRITE(6,1010) T,ITN
00008      WRITE(6,1011)
00009      DO 1001 I=2,N
00010      WRITE(6,1012) (I,(E(I,J),J=1,2))
00011      WRITE(6,1013)
00012      DO 1002 I=2,N
00013      WRITE(6,1014) (I,(F(I,J),J=1,4))
00014      WRITE(6,1015)
00015      DO 1003 I=2,N
00016      WRITE(6,1016) (I,(G(I,J),J=1,6))
00017 1010 FORMAT(1H1,/10X,'*** T = ',F10.5,', ITN = ',I5)
00018 1011 FORMAT(/,33X,> SELF-SIMILAR PROFILE EVALUATION <,
00019      & /,3X,'Z-POINT E(1)          E(2)')
00020 1012 FORMAT(5X,I2,1X,2(3X,F7.3))
00021 1013 FORMAT(/,3X,'Z-POINT F(1)      F(2)      F(3)      ',
00022      &           'F(4)')
00023 1014 FORMAT(5X,I2,1X,4(3X,F7.3))
00024 1015 FORMAT(/,3X,'Z-POINT G(1)      G(2)      G(3)      ',
00025      &           'G(4)      G(5)      G(6)')
00026 1016 FORMAT(5X,I2,1X,6(3X,F7.3))
00027 1020 CONTINUE
```

## APPENDIX B - TEA PROGAM LISTING

```
00001 C=====
00002 C      XCHECK2.FOR
00003 C-----
00004 C      PRINT VELOCITY INITIALIZATION DATA FOR DEBUG CHECKS
00005 C-----
00006 2000 IF(ICHECK.LT.500) GO TO 2060
00007      WRITE(6,2010) T,I,J
00008      WRITE(6,2020) C1,C2,C3,C4,C5
00009      WRITE(6,2050) THETA1,THETA2
00010      WRITE(6,2030) FLUXRI,FLUXMI,FLUXPI
00011      WRITE(6,2040) VE(J),BVALUE,CVALUE,B24AC
00012 2010 FORMAT(///,5X,'*** T = ',F7.4,' ; I = ',I2,' J = ',I2)
00013 2020 FORMAT(/,5X,'C1',8X,'C2',8X,'C3',8X,'C4',8X,'C5',
00014     & ,5X,5(F10.4,2X))
00015 2030 FORMAT(/2X,'FLUXRI = ',E12.4,
00016     & /2X,'FLUXMI = ',E12.4,/2X,'FLUXPI = ',E12.4)
00017 2040 FORMAT(/2X,'VE(J) = ',F10.4,/
00018     & 2X,'B = ',E12.4,' C = ',E12.4,' B24AC = ',E12.4)
00019 2050 FORMAT(/5X,'THETA1 = ',F10.5,' THETA2 = ',F10.5)
00020 2060 CONTINUE
00021 C=====
```

## APPENDIX B - TEA PROGAM LISTING

```
00001 C=====
00002 C      XCHECK3.FOR
00003 C-----
00004 C      KINETIC ENERGY EXCHANGE ERRORS
00005 C      Print out all kinetic energy information if the program bombs.
00006 C      This error by resetting the KE-CHANGE and re-computing VSTAR
00007 C-----
00008     WRITE(*,*) 
00009     WRITE(*,'(/5X,38H*** ERROR DURING CALCULATIONS FOR T = ,
00010       &           F10.5)') T
00011     WRITE(*,'(/10X,10HDKE    = ,F15.3,/10X,10HDKEOLD  = ,F15.3,
00012       &           /10X,10HSIGMA   = ,F15.3,/10X,10HPLOSS   = ,F15.3,
00013       &           /10X,10HENERGY1S= ,F15.3,/10X,10HCHANGE   = ,F15.3,
00014       &           /10X,10HVSTAR   = ,F15.3)')
00015     &      DKE,DKEOLD,SIGMA,PLOSS,ENERGY1S,CHANGE,VSTAR
00016     CHANGE = -0.999*ENERGY1S
00017     WRITE(*,'(/5X,38H*** PROCEED W/ CHANGE = -0.999ENERGY1S)')
00018     VSTAR = ((ENERGY1S+CHANGE)/(0.5*D1S))
00019     WRITE(*,'(/5X,19H*** NEW VSTAR IS = ,F15.3//)') VSTAR
00020 C=====
```

## APPENDIX B - TEA PROGAM LISTING

```
00001 C=====
00002 C      XCHECK4.FOR
00003 C-----
00004 C      PRINT ENTRAINED VELOCITY AND SURGE FOR ITERATIVE PROCESS
00005 C-----
00006 4000 IF(ICHECK.LT.1000) GO TO 4020
00007      WRITE(6,4010) V1S,SURGE
00008      4010 FORMAT(/,5X,'V1S = ',F10.3,',    SURGE = ',F10.3)
00009      4020 CONTINUE
00010 C-----
```

## APPENDIX C - TEST CASE INPUT LISTINGS

C----- CASE1.DAT ---  
C  
C Case study input file for TEA.FOR transient ejector analysis  
C routine. Here, a single step function is prescribed that  
C corresponds with one of the STOVL ejector tests run in June 1987.  
C This file assumes the default BACK and DISP parameters in the TEA.FOR  
C source code are appropriate.  
C  
C-----

CASE banner.

Test for step change in primary flow for STOVL ejector design.

GEOMetric approximation for the ejector.

X0	Y0		
0009.36000,	0001.25000		
X1	Y1	NX1	NY1
0000.10801,	0000.10801,	00012,	00003
X2	Y2		
0000.78000,	0000.34700		
X3	Y3		
0009.36000,	0001.04100		
X4	Y4		
0009.36000,	0001.87500		
Z1	NZ		
0000.90000,	00005		

COEFFicients for solution execution.

ITYPE	BETA	CSIGMA
00001,	0001.0550,	0000.30000

PRIMary nozzle discharge conditions.

SPECify states at each time step.

T	MDOT1P	T1PO	P1P
0000.00010,	0018.70000,	0769.70000,	2219.78000
0000.00020,	0018.70000,	0769.70000,	2219.78000
0000.00030,	0018.70000,	0769.70000,	2219.78000
0000.00040,	0018.70000,	0769.70000,	2219.78000
0000.00050,	0018.70000,	0769.70000,	2219.78000
0000.00060,	0021.85000,	0760.60000,	2250.92000
0000.00070,	0021.85000,	0760.60000,	2250.92000
0000.00080,	0021.85000,	0760.60000,	2250.92000
0			

C-----

## APPENDIX C - TEST CASE INPUT LISTINGS

```

00001
00002 C----- CASE2.DAT ---
00003 C
00004 C      This case study has the same basic conditions as CASE1.DAT, but includes
00005 C      the use of some optional macros.
00006 C
00007 C-----+
00008
00009 CASE banner.
00010     Test for step change in primary flow for STVOL ejector design.
00011
00012 DISPLAY parameters for printing and plotting output.
00013 ICHECK      INDEX      IPLOT
00014 00100,     00001,     00001
00015
00016 GEOMETRIC approximation for the ejector.
00017 X0          Y0
00018 0009.36000, 0001.25000
00019 X1          Y1          NX1      NY1
00020 0000.10801, 0000.10801, 00012, 00003
00021 X2          Y2
00022 0000.78000, 0000.34700
00023 X3          Y3
00024 0009.36000, 0001.04100
00025 X4          Y4
00026 0009.36000, 0001.87500
00027 Z1          NZ
00028 0000.90000, 00005
00029
00030 COEFFicients for solution execution.
00031 ITYPE        BETA        CSIGMA
00032 00001,       0001.0550,  0000.30000
00033
00034 FREE stream fluid conditions.
00035 TINF         PINF        GAMMA      RBAR        UINF        ALPHA
00036 0542.80000, 2067.84000, 0001.40000, 1714.54130, 0000.00000, 0090.00000
00037
00038 BACKpressure for ejector discharge
00039 2067.84000
00040
00041 PRIMary nozzle discharge conditions.
00042 SPECify states at each time step.
00043 T            MDOT1P      T1P0        P1P
00044 0000.00010, 0018.70000, 0769.70000, 2219.78000
00045 0000.00020, 0018.70000, 0769.70000, 2219.78000
00046 0000.00030, 0018.70000, 0769.70000, 2219.78000
00047 0000.00040, 0018.70000, 0769.70000, 2219.78000
00048 0000.00050, 0018.70000, 0769.70000, 2219.78000
00049 0000.00060, 0021.85000, 0760.60000, 2250.92000
00050 0000.00070, 0021.85000, 0760.60000, 2250.92000
00051 0000.00080, 0021.85000, 0760.60000, 2250.92000
00052 0000.00090, 0021.85000, 0760.60000, 2250.92000
00053 0000.00100, 0021.85000, 0760.60000, 2250.92000
00054 0000.00110, 0021.85000, 0760.60000, 2250.92000
00055 0000.00120, 0021.85000, 0760.60000, 2250.92000
00056 0000.00130, 0021.85000, 0760.60000, 2250.92000
00057 QUIT primary nozzle data input
00058
00059 STOP reading DATA

```

## APPENDIX D - OUTPUT LISTING FOR CASE 1

\*\*\*\*\* TEA INPUT \*\*\*\*\*

Test for step change in primary flow for STVOL ejector design.

CHECK PRINT LEVEL IS 100

EJECTOR GEOMETRIC CHARACTERISTICS,

X0 =	9.36000	Y0 =	1.25000
X1 =	0.10801	Y1 =	0.10801
NX1=	12	NY1=	3
X2 =	0.78000	Y2 =	0.34700
X3 =	9.36000	Y3 =	1.04100
X4 =	9.36000	Y4 =	1.87500
Z1 =	0.90000	NZ =	5

MIXING LOSS CORRECTION FACTOR

BETA = 1.05500

KINETIC ENERGY MIXING COEFFICIENT

CSIGMA = 0.30000

FREE-STREAM THERMODYNAMIC PROPERTIES

STATIC TEMPERATURE	= 542.79999 DEG-RANKINE
STATIC PRESSURE	= 2067.84009 LB-F/FT3
SPECIFIC HEAT RATIO	= 1.40000
GAS CONSTANT, AIR	= 1714.54126 FT2/S2-R
FREESTREAM VELOCITY	= 0.00000 FT/S
ANGLE-OF-ATTACK	= 90.00000 DEGREES

EJE BACK PRESSURE IS 2067.84009 LBF/FT2

PRIMARY NOZZLE DATA

DATA SET#	T (sec)	DMPDT (lbm/s)	T1P0 (degR)	P1P (lbf/ft2)
1	0.00040	18.70000	769.70001	2219.78003
2	0.00050	18.70000	769.70001	2219.78003
3	0.00060	21.85000	760.59998	2250.91992
4	0.00070	21.85000	760.59998	2250.91992
5	0.00080	21.85000	760.59998	2250.91992

PROGRAM WILL OPERATE ON 5 DATA SETS

## APPENDIX D - OUTPUT LISTING FOR CASE 1

\*\*\*\*\* SINGLE POINT CALCULATION \*\*\*\*\*  
 T = 0.00040 sec

### FIELD VARIABLE PROFILE:

Station -> Infinity	1P	1S	3	4	
AREA	11.70000	0.41998	9.32378	9.74376	17.55000 FT
V	0.00000	769.94739	282.19669	304.57248	164.99725 FT/S
P	2067.84009	2219.78003	1980.71228	1997.96570	2067.84009 LBF/FT2
P0	2067.84009	2799.79346	2067.84009	2097.37158	2097.37158 LBF/FT2
T	542.79999	720.30579	536.16473	553.28766	558.74860 DEG-R
TO	542.79999	769.70001	542.79999	561.01691	561.01691 DEG-R
RHO	0.07149	0.05783	0.06932	0.06776	0.06945 LBM/FT3
MDOT	0.00000	18.70000	182.39970	201.09969	201.09970 LBM/S

#### NOTES:

Nozzle Pressure Ratio is 1.35397 (Choked NPR is 1.89293 )  
 Station 3-4 SURGE error is 0.00002361  
 Solution obtained in 17 iterations, limit is 50

### FINITE VOLUME PROFILE

Station	Z	B_inner	B_outer	B_jsl
2	0.18000E+00	0.12857E-02	0.42297E-01	0.10382E-01
3	0.36000E+00	0.00000E+00	0.67784E-01	0.16039E-01
4	0.54000E+00	0.00000E+00	0.93272E-01	0.19376E-01
5	0.72000E+00	0.00000E+00	0.11876E+00	0.21867E-01
6	0.90000E+00	0.00000E+00	0.14425E+00	0.23816E-01

Station	Rho	P	Vm	Ve
1	0.17974E-02	0.22198E+04	0.76995E+03	0.28220E+03
2	0.20635E-02	0.19575E+04	0.10653E+04	0.27064E+03
3	0.20895E-02	0.19822E+04	0.73541E+03	0.27064E+03
4	0.20987E-02	0.19909E+04	0.59600E+03	0.27064E+03
5	0.21033E-02	0.19953E+04	0.52124E+03	0.27064E+03
6	0.21061E-02	0.19980E+04	0.47450E+03	0.27064E+03

Element	D(Rho)/DT	D(P)/DT	D(Vm)/DT	D(Ve)/DT
1	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
2	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
3	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
4	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
5	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00

#### NOTES:

Inner jet expansion, Theta1 0.08603 radians  
 Outer jet expansion, Theta2 0.14066 radians  
 Initial jet with, B0, 0.01681 Ft  
 Allowable jet width, Bmax, 0.39000 Ft

### PREDICTED THRUST AND PERFORMANCE:

Total ejector thrust = 926.57001 Lb  
 Isentropic primary thrust = 508.74969 Lb  
 Thrust augmentation ratio = 1.82127

## APPENDIX D - OUTPUT LISTING FOR CASE 1

\*\*\*\*\* SINGLE POINT CALCULATION \*\*\*\*\*  
 T = 0.00050 sec

### FIELD VARIABLE PROFILE:

Station -> Infinity	1P	1S	3	4	
AREA	11.70000	0.41998	9.32378	9.74376	17.55000 FT
V	0.00000	769.94739	282.19650	304.57236	164.98514 FT/S
P	2067.84009	2219.78003	1980.71240	1997.96570	2067.99219 LBF/FT2
P0	2067.84009	2799.79346	2067.84009	2097.37158	2097.37158 LBF/FT2
T	542.79999	720.30579	536.16474	553.28766	558.74890 DEG-R
T0	542.79999	769.70001	542.79999	561.01691	561.01691 DEG-R
RHO	0.07149	0.05783	0.06932	0.06776	0.06945 LBM/FT3
MDOT	0.00000	18.70000	182.39959	201.09961	201.09961 LBM/S

NOTES:

Nozzle Pressure Ratio is 1.35397 (Choked NPR is 1.89293 )

### FINITE VOLUME PROFILE

Station	Z	B_inner	B_outer	B_js1
2	0.18000E+00	0.12857E-02	0.42297E-01	0.10382E-01
3	0.36000E+00	0.00000E+00	0.67784E-01	0.16039E-01
4	0.54000E+00	0.00000E+00	0.93272E-01	0.19376E-01
5	0.72000E+00	0.00000E+00	0.11876E+00	0.21867E-01
6	0.90000E+00	0.00000E+00	0.14425E+00	0.23816E-01

Station	Rho	P	Vm	Ve
1	0.17974E-02	0.22198E+04	0.76995E+03	0.28220E+03
2	0.20635E-02	0.19575E+04	0.10653E+04	0.27064E+03
3	0.20895E-02	0.19822E+04	0.73541E+03	0.27064E+03
4	0.20987E-02	0.19909E+04	0.59600E+03	0.27064E+03
5	0.21033E-02	0.19953E+04	0.52124E+03	0.27064E+03
6	0.21061E-02	0.19980E+04	0.47450E+03	0.27064E+03

Element	D(Rho)/DT	D(P)/DT	D(Vm)/DT	D(Ve)/DT
1	0.00000E+00	0.44516E+00	0.71454E-02	-0.18450E+01
2	0.00000E+00	0.22258E+00	0.61080E-02	-0.18450E+01
3	0.42453E-06	0.44516E+00	0.57823E+00	-0.18450E+01
4	-0.42453E-06	0.22258E+00	-0.44430E+00	-0.18450E+01
5	-0.42453E-06	-0.22258E+00	-0.37205E+00	-0.18450E+01

NOTES:

Inner jet expansion, Theta1 0.08603 radians  
 Outer jet expansion, Theta2 0.14066 radians  
 Initial jet width, B0, 0.01681 Ft  
 Allowable jet width, Bmax, 0.39000 Ft

### PREDICTED THRUST AND PERFORMANCE:

Total ejector thrust = 926.50159 Lb  
 Isentropic primary thrust = 508.74969 Lb  
 Thrust augmentation ratio = 1.82113

APPENDIX D - OUTPUT LISTING FOR CASE 1

\*\*\*\*\* SINGLE POINT CALCULATION \*\*\*\*\*  
 T = 0.00060 sec

**FIELD VARIABLE PROFILE:**

Station -> Infinity	1P	1S	3	4	
AREA	11.70000	0.41998	9.32378	9.74376	17.55000 FT
V	0.00000	860.78772	282.19669	303.30927	164.33514 FT/S
P	2067.84009	2250.91992	1980.71228	1998.06897	2067.49927 LBF/FT2
P0	2067.84009	3027.15869	2067.84009	2096.64307	2096.64307 LBF/FT2
T	542.79999	698.86292	536.16473	553.28772	558.70282 DEG-R
TO	542.79999	760.59998	542.79999	560.95300	560.95300 DEG-R
RHO	0.07149	0.06044	0.06932	0.06777	0.06944 LBM/FT3
MDOT	0.00000	21.85001	182.39970	200.27596	200.27597 LBM/S

**NOTES:**

Nozzle Pressure Ratio is 1.46392 (Choked NPR is 1.89293 )

**FINITE VOLUME PROFILE**

Station	Z	B_inner	B_outer	B_js1
2	0.18000E+00	0.46881E-04	0.41181E-01	0.11199E-01
3	0.36000E+00	0.00000E+00	0.65551E-01	0.15560E-01
4	0.54000E+00	0.00000E+00	0.89922E-01	0.18624E-01
5	0.72000E+00	0.00000E+00	0.11429E+00	0.20934E-01
6	0.90000E+00	0.00000E+00	0.13866E+00	0.22756E-01

Station	Rho	P	Vm	Ve
1	0.18785E-02	0.22509E+04	0.86079E+03	0.28220E+03
2	0.20719E-02	0.19656E+04	0.10916E+04	0.27064E+03
3	0.20910E-02	0.19836E+04	0.73827E+03	0.27068E+03
4	0.20992E-02	0.19914E+04	0.59681E+03	0.27068E+03
5	0.21036E-02	0.19955E+04	0.52150E+03	0.27068E+03
6	0.21063E-02	0.19981E+04	0.47460E+03	0.27068E+03

Element	D(Rho)/DT	D(P)/DT	D(Vm)/DT	D(Ve)/DT
1	0.83474E-01	0.80936E+05	0.26340E+06	0.18311E+01
2	0.14618E-01	0.14168E+05	0.28578E+05	0.18311E+01
3	0.57034E-02	0.54621E+04	0.80213E+04	0.18311E+01
4	0.23664E-02	0.22534E+04	0.26043E+04	0.18311E+01
5	0.10866E-02	0.10325E+04	0.98203E+03	0.18311E+01

**NOTES:**

Inner jet expansion, Theta1 0.09286 radians  
 Outer jet expansion, Theta2 0.13457 radians  
 Initial jet width, B0, 0.01681 Ft  
 Allowable jet width, Bmax, 0.39000 Ft

**PREDICTED THRUST AND PERFORMANCE:**

Total ejector thrust = 919.07166 Lb  
 Isentropic primary thrust = 659.06592 Lb  
 Thrust augmentation ratio = 1.39451

## APPENDIX D - OUTPUT LISTING FOR CASE 1

\*\*\*\*\* SINGLE POINT CALCULATION \*\*\*\*\*  
 T = 0.00070 sec

### FIELD VARIABLE PROFILE:

Station -> Infinity	1P	1S	3	4	
AREA	11.70000	0.41998	9.32378	9.74376	17.55000 FT
V	0.00000	860.78772	280.10501	301.62244	163.46561 FT/S
P	2067.84009	2250.91992	1981.97961	1998.23413	2066.87256 LBF/FT2
P0	2067.84009	3027.15869	2067.84009	2095.70337	2095.70337 LBF/FT2
T	542.79999	698.86292	536.26273	553.28790	558.64166 DEG-R
T0	542.79999	760.59998	542.79999	560.86810	560.86810 DEG-R
RHO	0.07149	0.06044	0.06936	0.06777	0.06943 LBM/FT3
MDOT	0.00000	21.85001	181.13047	199.17854	199.17854 LBM/S

NOTES:

Nozzle Pressure Ratio is 1.46392 (Choked NPR is 1.89293 )

### FINITE VOLUME PROFILE

Station	Z	B_inner	B_outer	B_js1
2	0.18000E+00	0.00000E+00	0.41214E-01	0.11696E-01
3	0.36000E+00	0.00000E+00	0.65618E-01	0.15927E-01
4	0.54000E+00	0.00000E+00	0.90023E-01	0.18886E-01
5	0.72000E+00	0.00000E+00	0.11443E+00	0.21151E-01
6	0.90000E+00	0.00000E+00	0.13883E+00	0.22978E-01

Station	Rho	P	Vm	Ve
1	0.18785E-02	0.22509E+04	0.86079E+03	0.28011E+03
2	0.20775E-02	0.19712E+04	0.11092E+04	0.26850E+03
3	0.20937E-02	0.19863E+04	0.74354E+03	0.26858E+03
4	0.21005E-02	0.19926E+04	0.59852E+03	0.26859E+03
5	0.21041E-02	0.19960E+04	0.52205E+03	0.26860E+03
6	0.21064E-02	0.19982E+04	0.47475E+03	0.26860E+03

Element	D(Rho)/DT	D(P)/DT	D(Vm)/DT	D(Ve)/DT
1	0.56055E-01	0.55826E+05	0.17555E+06	-0.20917E+05
2	0.27180E-01	0.26487E+05	0.52730E+05	-0.20917E+05
3	0.12250E-01	0.11782E+05	0.17126E+05	-0.20917E+05
4	0.50163E-02	0.47934E+04	0.54920E+04	-0.20917E+05
5	0.17346E-02	0.16524E+04	0.15618E+04	-0.20917E+05

NOTES:

Inner jet expansion, Theta1 0.09330 radians  
 Outer jet expansion, Theta2 0.13476 radians  
 Initial jet width, B0, 0.01681 Ft  
 Allowable jet width, Bmax, 0.39000 Ft

### PREDICTED THRUST AND PERFORMANCE:

Total ejector thrust = 909.19916 Lb  
 Isentropic primary thrust = 659.06592 Lb  
 Thrust augmentation ratio = 1.37953

## APPENDIX D - OUTPUT LISTING FOR CASE 1

\*\*\*\*\* SINGLE POINT CALCULATION \*\*\*\*\*  
 T = 0.00080 sec

### FIELD VARIABLE PROFILE:

Station -> Infinity	1P	1S	3	4	
AREA	11.70000	0.41998	9.32378	9.74376	17.55000 FT
V	0.00000	860.78772	282.21085	303.42273	164.39374 FT/S
P	2067.84009	2250.91992	1980.70361	1998.74744	2068.25391 LBF/FT2
P0	2067.84009	3027.15869	2067.84009	2097.42896	2097.42896 LBF/FT2
T	542.79999	698.86292	536.16406	553.28845	558.70764 DEG-R
TO	542.79999	760.59998	542.79999	560.95941	560.95941 DEG-R
RHO	0.07149	0.06044	0.06932	0.06779	0.06947 LBM/FT3
MDOT	0.00000	21.85001	182.40828	200.41866	200.41867 LBM/S

NOTES:

Nozzle Pressure Ratio is 1.46392 (Choked NPR 1s 1.89293 )

### FINITE VOLUME PROFILE

Station	Z	B_inner	B_outer	B_js1
2	0.18000E+00	0.47418E-04	0.41180E-01	0.11992E-01
3	0.36000E+00	0.00000E+00	0.65550E-01	0.16289E-01
4	0.54000E+00	0.00000E+00	0.89920E-01	0.19109E-01
5	0.72000E+00	0.00000E+00	0.11429E+00	0.21208E-01
6	0.90000E+00	0.00000E+00	0.13866E+00	0.22894E-01

Station	Rho	P	Vm	Ve
1	0.18785E-02	0.22509E+04	0.86079E+03	0.28221E+03
2	0.20811E-02	0.19748E+04	0.11206E+04	0.27057E+03
3	0.20969E-02	0.19894E+04	0.74972E+03	0.27066E+03
4	0.21024E-02	0.19945E+04	0.60126E+03	0.27069E+03
5	0.21051E-02	0.19970E+04	0.52321E+03	0.27069E+03
6	0.21070E-02	0.19987E+04	0.47524E+03	0.27070E+03

Element	D(Rho)/DT	D(P)/DT	D(Vm)/DT	D(Ve)/DT
1	0.36388E-01	0.35501E+05	0.11427E+06	0.21058E+05
2	0.31656E-01	0.30789E+05	0.61846E+05	0.21058E+05
3	0.19465E-01	0.18730E+05	0.27408E+05	0.21058E+05
4	0.10562E-01	0.10093E+05	0.11643E+05	0.21058E+05
5	0.53912E-02	0.51329E+04	0.48831E+04	0.21058E+05

NOTES:

Inner jet expansion, Theta1 0.09286 radians  
 Outer jet expansion, Theta2 0.13457 radians  
 Initial jet width, B0, 0.01681 Ft  
 Allowable jet width, Bmax, 0.39000 Ft

### PREDICTED THRUST AND PERFORMANCE:

Total ejector thrust = 920.05444 Lb  
 Isentropic primary thrust = 659.06592 Lb  
 Thrust augmentation ratio = 1.39600

APPENDIX D - OUTPUT LISTING FOR CASE 1

\*\*\*\*\* SOLUTION PROFILE \*\*\*\*\*

T (m-sec)	DMpDT (1bm/s)	THRUST (1b)	PHI
0.40000	18.70000	926.57001	1.82127
0.50000	18.70000	926.50159	1.82113
0.60000	21.85001	919.07166	1.39451
0.70000	21.85001	909.19916	1.37953
0.80000	21.85001	920.05444	1.39600

## **REFERENCES**

1. Drummond, C.K.: A Control-Volume Method for Analysis of Unsteady Thrust Augmenting Ejector Flows. NASA CR-182203, 1988.
2. Drummond, C.K.: Transient Flow Thrust Prediction for an Ejector Propulsion Concept. NASA TM-102078, 1989.
3. Drummond, C.K.: Preliminary Dynamic Tests of a Flight-Type Ejector. NASA TM-105814, 1992.
4. Drummond, C.K., and Barankiewicz, W.S.: A Modeling Technique for STOVL Ejector and Volume Dynamics. NASA TM-103167, 1990.
5. Drummond, C.K., and Ouzts, P.J.: Real-Time Simulation of an F110/STOVL Turbofan Engine. NASA TM-102409, 1989.

TABLE I. - EJECTOR GEOMETRY FOR STOVL TEST CASE  
 [Configuration for 12 nozzles; 112-in. wide duct; 3 orifices per nozzle.]

Station	Direction			
	X	Y	Z	
Characteristic dimension, ft.				
0	9.333	1.875	0.900	
1	.108	.108	.900	
2	.778	.347	-	
3	9.333	1.042	2.917	
4	9.333	1.875	-	
Mixing region				
Volume, dV	Area, dA	Scale factors		
		Number of Units		
		$n_x$	$n_y$	
$Wdx dz = z_1$	$Wdx$	12	3	$N = n_x n_y$
$Wdx = z_1 A$				36

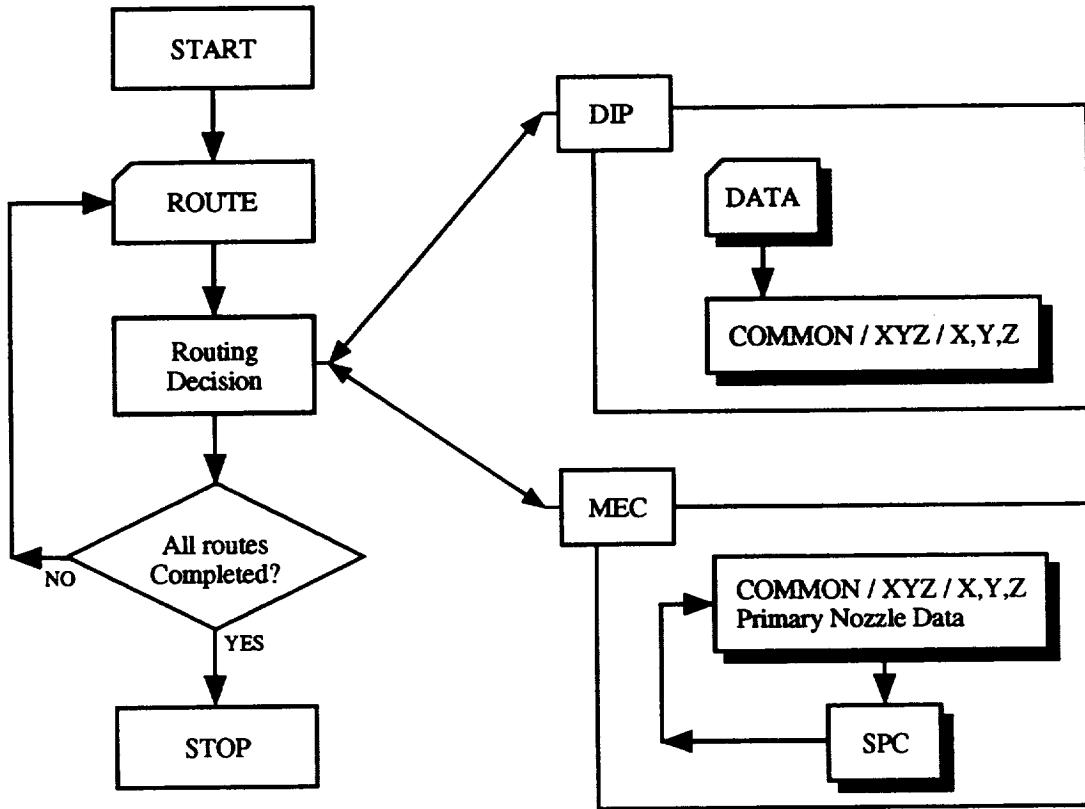


Figure 1. - General program structure.

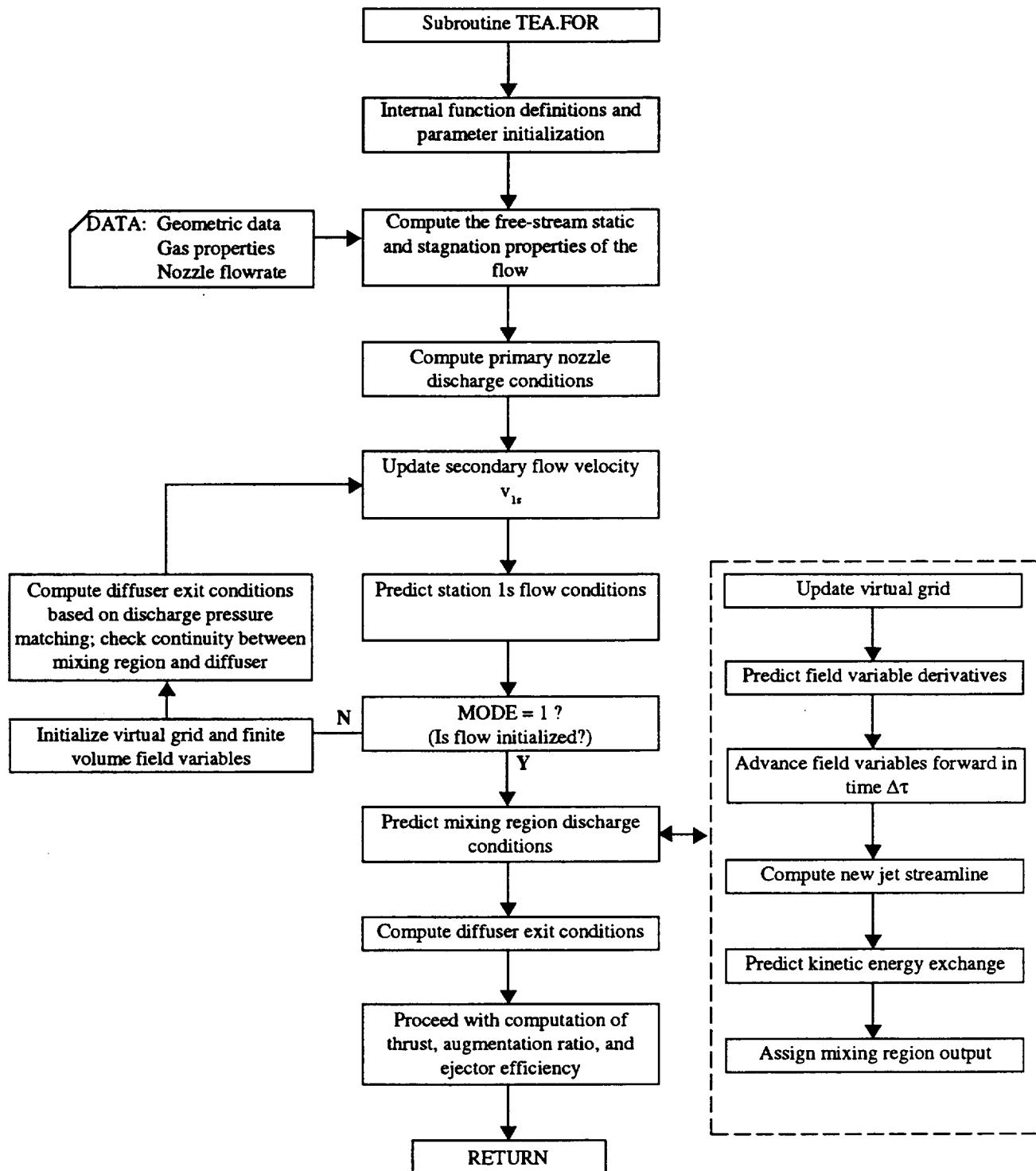


Figure 2 - Outline of the SPC solution procedure.

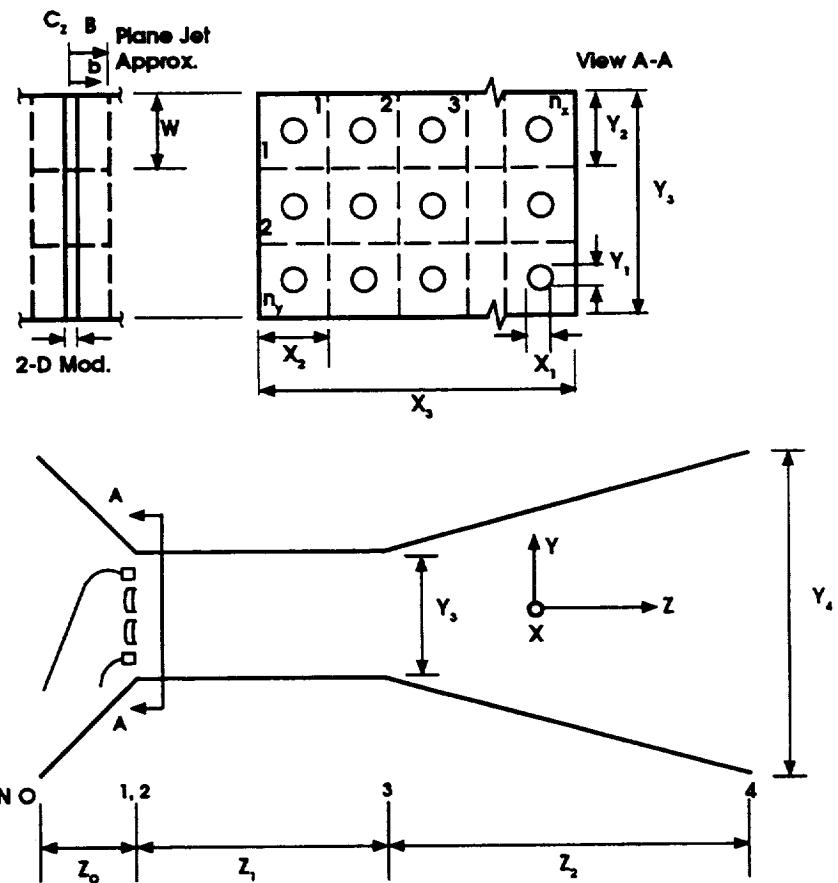


Figure 3. - Geometric ejector approximation.

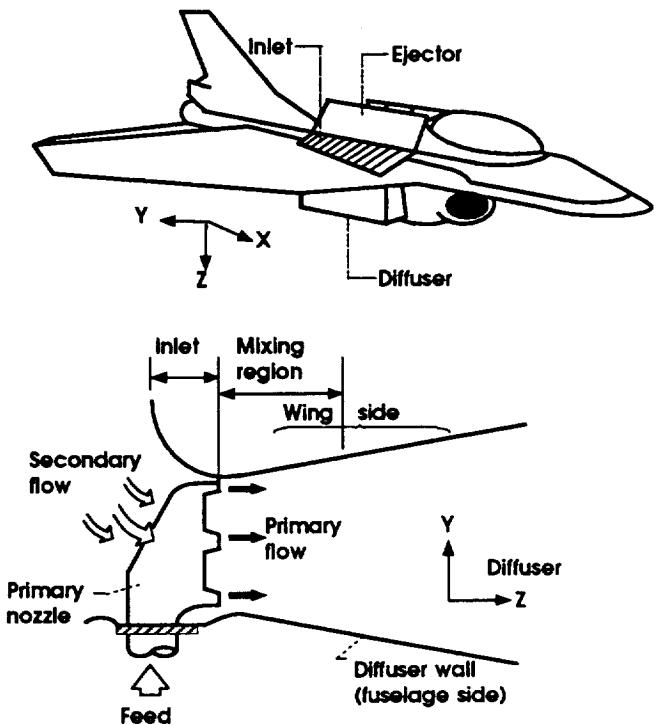


Figure 4. - STOVL ejector application.

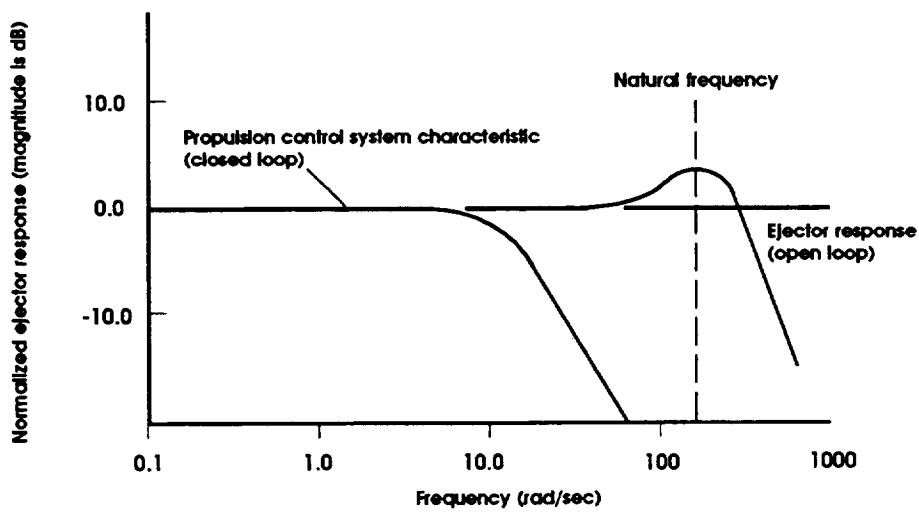


Figure 5. - Quasi-steady response criteria.

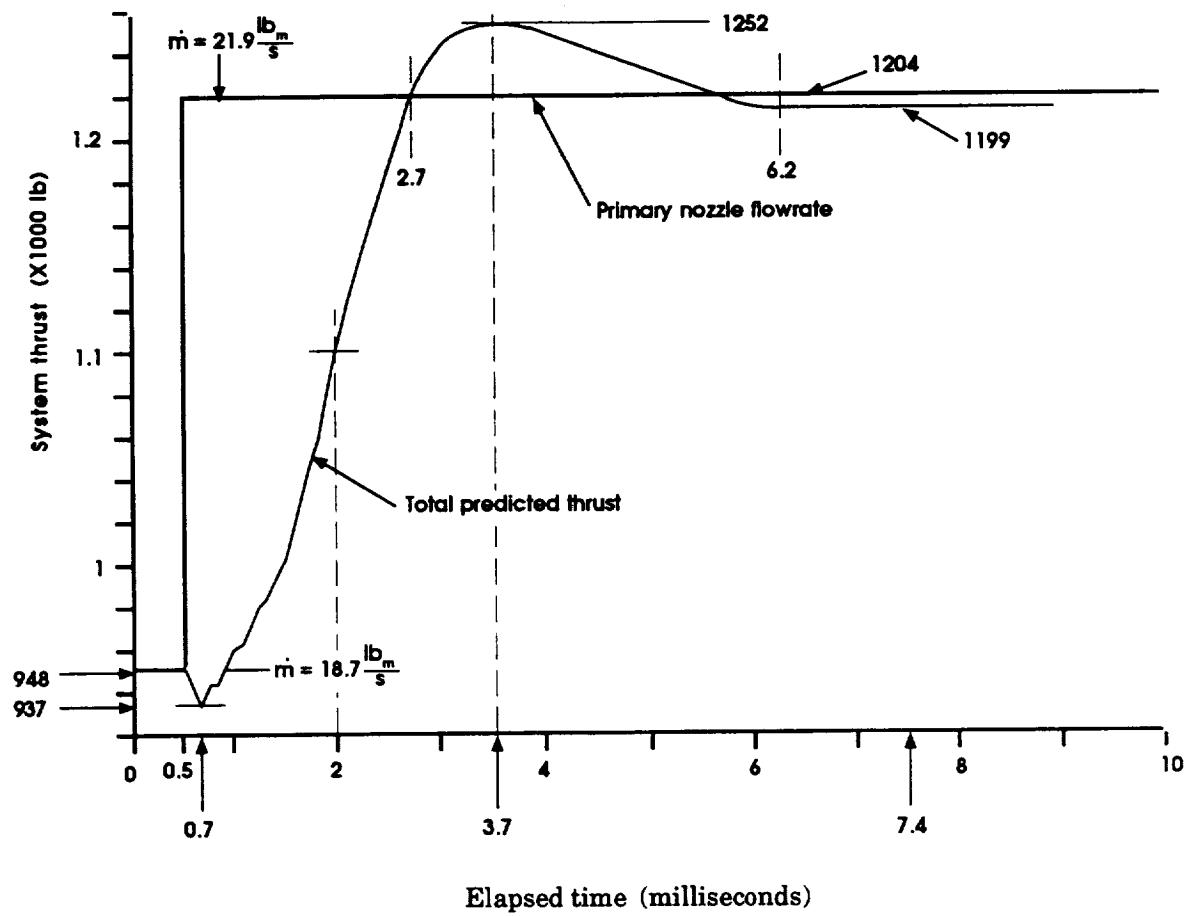


Figure 6. - Result from transient flow test case.

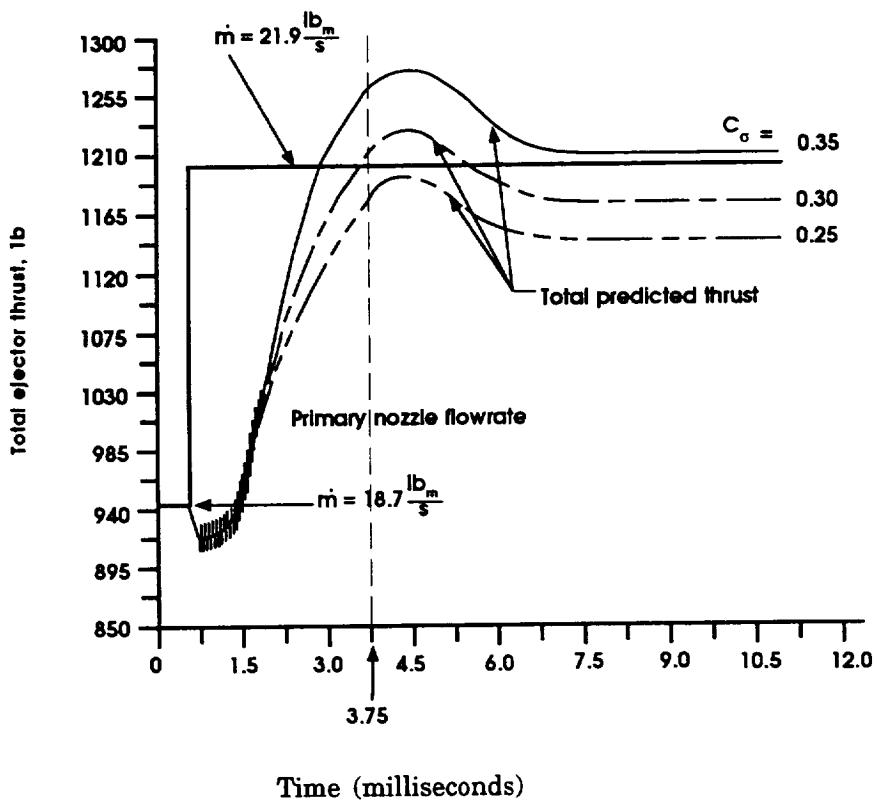


Figure 7. - Effects of CSIGMA on thrust prediction.

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A FORTRAN computer program for the semianalytic prediction of unsteady thrust augmenting ejector performance has been developed, based on a theoretical analysis for ejectors. That analysis blends classic self-similar turbulent jet descriptions with control-volume mixing region elements. Division of the ejector into an inlet, diffuser, and mixing region allowed flexibility in the modelling of the physics for each region. In particular, the inlet and diffuser analyses are simplified by a quasi-steady-analysis, justified by the assumption that pressure is the forcing function in those regions. Only the mixing region is assumed to be dominated by viscous effects. The present work provides an overview of the code structure, a description of the required input and output data file formats, and the results for a test case. Since there are limitations to the code for applications outside the bounds of the test case, the user should consider TEA as a research code (not as a production code), designed specifically as an implementation of the proposed ejector theory. Program error flags are discussed, and some diagnostic routines are presented.			
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